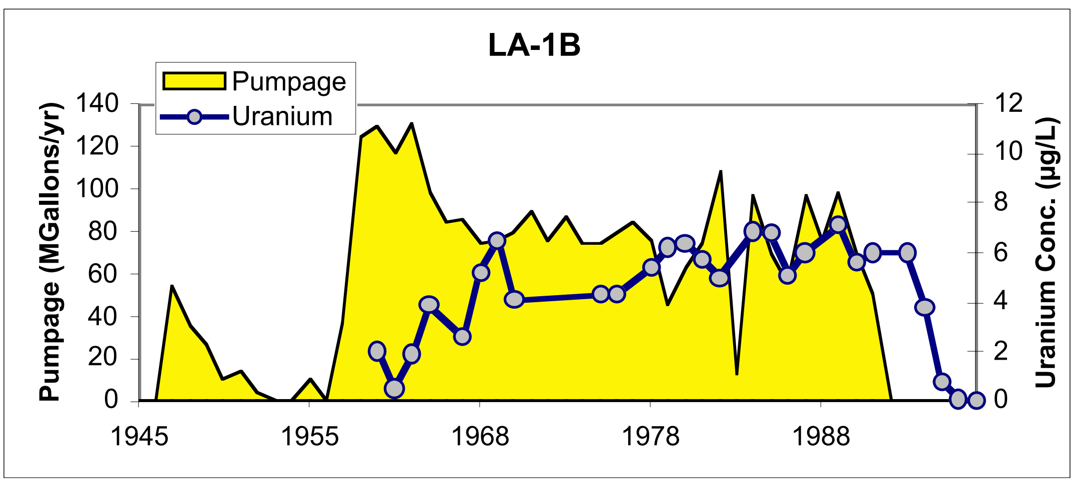
LA-14046

Uranium in Waters near Los Alamos National Laboratory: Concentrations, Trends, and Isotopic Composition through 1999



Los Alamos
NATIONAL LABORATORY

Edited by Hector Hinojosa, Group IM-1
Prepared by Belinda Gutierrez, Group RRES-ECO

Cover illustration: Annual pumpage volumes and uranium concentrations in groundwater withdrawn from Well LA-1B located in the Los Alamos well field, 1945 to 1995.

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B. M. Gallaher
D. W. Efurd
R. E. Steiner

Los Alamos
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EXECUTIVE SUMMARY

The Los Alamos National Laboratory (LANL or Laboratory) has used significant quantities of uranium in its research. A key concern is whether these operations have impacted the regional drinking water aquifer or the Rio Grande. In this study we looked for evidence of LANL-derived uranium in nearly 100 water sources near Los Alamos.

Using a precise analytical "fingerprinting" method, we tested for uranium concentrations and composition in waters from wells, springs, streams, and rivers near the Laboratory. The analytical method helps us distinguish between naturally occurring uranium and uranium that may have come from the Laboratory. Natural uranium actually is a well-defined mixture of various forms (isotopes) of uranium, while much of the LANL uranium has artificially adjusted proportions of the isotopes uranium-235, -236, and -238. If uranium from the Laboratory enters a water body, the uranium mixture will be altered from that found in nature and will be detectable with the "fingerprinting" method.

We found only 2 of 93 water samples with uranium concentrations greater than the US Environmental Protection Agency (EPA) Maximum Contaminant Level of 30 μg/L in public drinking water systems. Both of these higher values were found in San Ildefonso Pueblo wells in the Rio Grande valley and contain natural uranium commonly found in this area. Natural uranium mineral deposits are concentrated in northeastern Santa Fe County, and uranium can leach from these deposits into groundwater.

All of the samples analyzed within or adjacent to the Laboratory met the EPA drinking water limit. If the Laboratory impacts were severe, we would expect to find high concentrations within and beneath the facility. This review showed the opposite—uranium concentrations in the Los Alamos drinking water aquifer are among the lowest in the region.

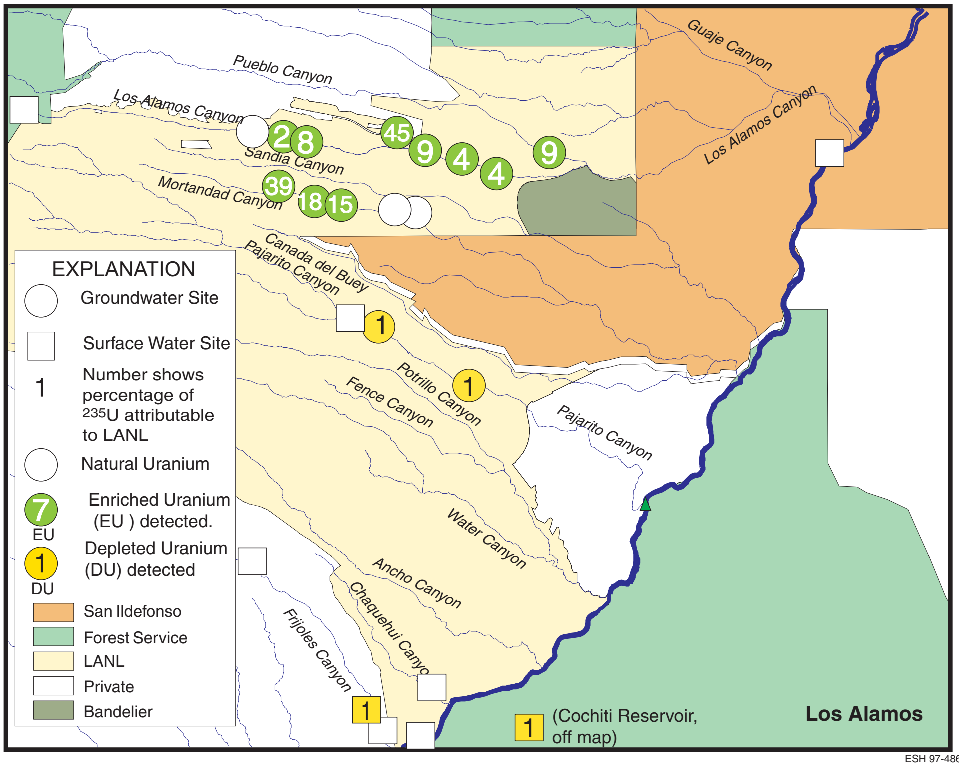
Shallow groundwaters found in the bottoms of four LANL canyons contain Laboratory-derived uranium. The highest uranium concentration in these canyon waters was 13 μg/L, less than half the EPA standard.

In the deeper groundwaters, we were able to confirm Laboratory-derived uranium that is depleted in uranium-235 (compared to natural uranium) in waters issuing from Ancho Spring, a relatively large spring on the Laboratory near the Rio Grande. However, because the spring emerges through stream sediments that also contain depleted uranium, we are uncertain whether the depleted uranium is associated with the groundwater or the stream sediments. The uranium concentration in Ancho Spring was 0.7 μg/L, about 2 percent of the EPA standard.

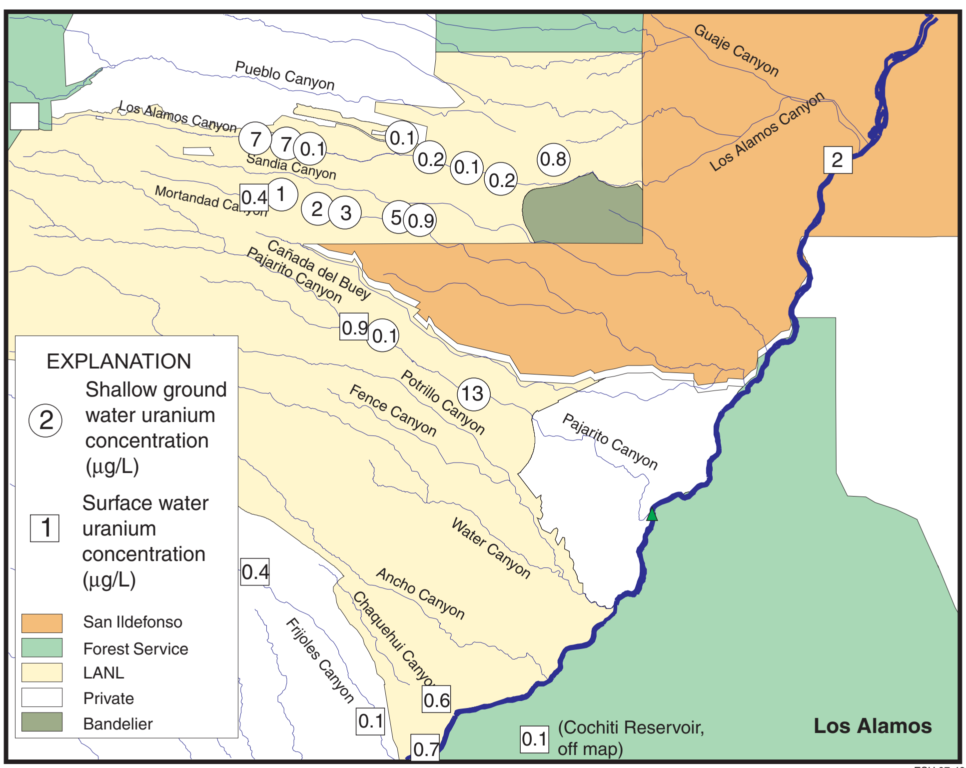
The highest concentration measured in the Rio Grande or Frijoles Creek was 2 μg/L. We calculate that less than 1 percent of the uranium-235 in these streams was Laboratory-derived. Uranium concentrations in the Rio Grande upstream of the Laboratory are statistically indistinguishable from those measured below LANL.

We reviewed historical uranium results available since the 1950s for trends. We identified rising levels in regional aquifer uranium concentrations in lower Los Alamos Canyon and lower Pueblo Canyon. Natural uranium was found at both sites. The causes of the rises appear to be related to hydrologic changes in these areas—the former related to drawing native uranium-rich groundwater into wells by pumping, and the latter likely related to increased leaching of uranium from stream sediments by artificial effluent streams.

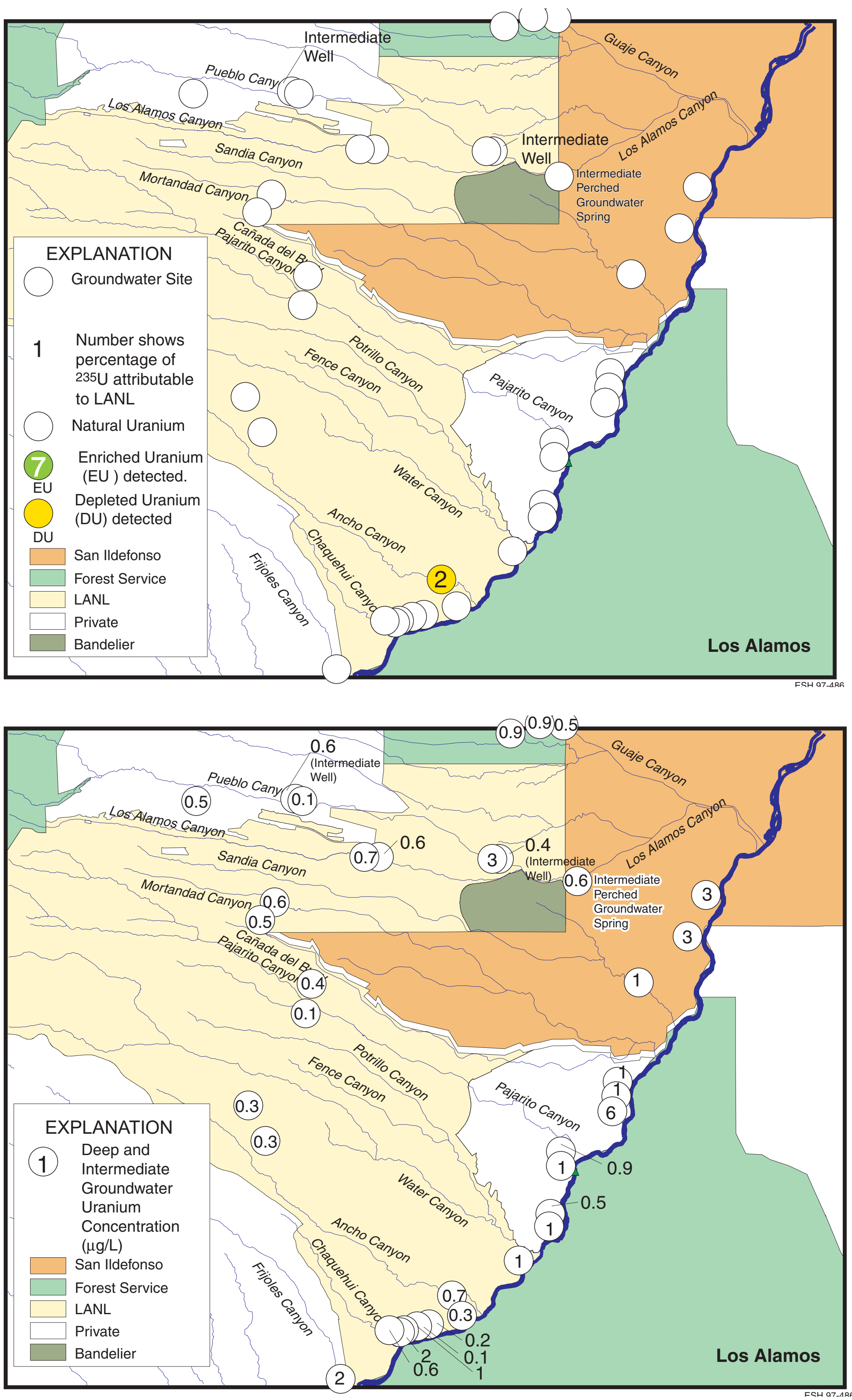
The following maps show where we have confirmed Laboratory-derived uranium in groundwaters, where natural uranium is found, and their associated concentrations.



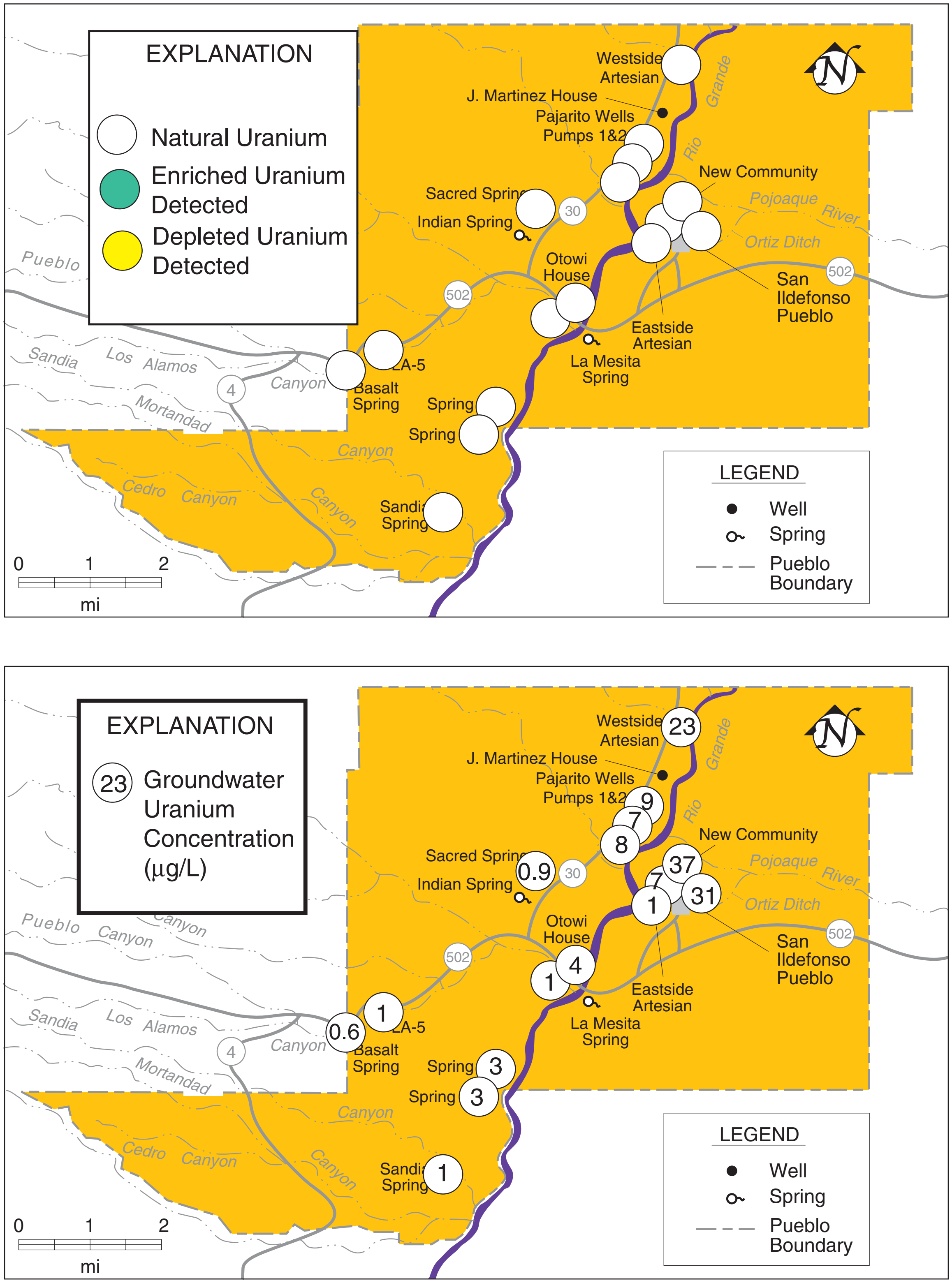
Shallow wells (circles) and surface waters (squares) analyzed for presence of Laboratory-derived uranium



Type of uranium found in shallow wells and surface water stations near Los Alamos (top) and measured total uranium concentrations (bottom).



Type of uranium found in springs and deep and intermediate wells near Los Alamos (top) and measured total uranium concentrations (bottom).



Type of uranium found in springs and regional aquifer wells on or adjacent to San Ildefonso Pueblo (top) and measured total uranium concentrations (bottom).

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by

B. M. Gallaher, D. W. Efurd, and R. E. Steiner

ABSTRACT

This report documents a survey of Los Alamos waters for uranium derived from the Los Alamos National Laboratory (LANL). Using precise analytical isotopic "fingerprinting" techniques (thermal ionization mass spectrometry, or TIMS) we measured naturally occurring and isotopically modified (LANL-derived) forms of uranium in surface water and groundwater samples. To add further perspective, we compiled historical uranium monitoring results for the region, looked for trends, and compared to the TIMS results.

Only two of the 93 water samples collected for this survey contained total uranium concentrations greater than the US Environmental Protection Agency (EPA) standard for drinking water systems (30 μg/L). The two samples greater than the standard were from wells located in San Ildefonso Pueblo and contain natural uranium commonly found in waters and sediments of the Rio Grande valley. The highest concentration measured in Rio Grande surface water 1990–1999 was 7 μg/L, one-fourth the drinking water standard. Within LANL, total uranium concentrations measured in this survey were typically low, averaging about 1 μg/L and with a maximum concentration of 13 μg/L, less than half the EPA standard. These concentrations are notably lower than those estimated for past effluent discharges of more than 1,000 μg/L, and the available information suggests considerable natural attenuation of past Laboratory releases. Current effluents contain uranium at a fraction of the standard.

Most (91%) of the TIMS water samples showed natural uranium isotopic composition. All but one of the confirmed detections of LANL uranium in groundwater were in samples taken from perched alluvial groundwater contained within the floors of LANL canyons. In deeper groundwater, we confirmed depleted uranium in samples from Ancho Spring, a relatively large spring on LANL lands issuing near the Rio Grande. It is uncertain whether the depleted uranium is associated with the groundwater or with stream channel sediments through which the spring issues. Enriched uranium was measured in some initial deep groundwater samples, but we were unable to verify any of these indications through repeat testing or through review of historical sampling results. When all TIMS results are averaged, natural isotopic compositions are indicated for each well or spring in which enriched uranium was initially measured.

Overall, uranium-235 that can be attributed to the Laboratory usually comprises less than 2 percent of the total, reaching a maximum of about 40 percent in alluvial groundwater below effluent discharge points. In off-site surface waters, the proportion of LANL uranium-235 measured in the Rio Grande and Frijoles Creek was 1 percent or less of the total. Statistically, uranium concentrations in the Rio Grande upstream of the Laboratory are indistinguishable from those measured downstream.

We identified upward trends in regional aquifer uranium concentrations at two locations: lower Los Alamos Canyon and lower Pueblo Canyon. TIMS results at both sites indicate the uranium to be of natural isotopic composition. We suggest the uranium rise in lower Los Alamos Canyon is related to large-scale municipal pumping effects, temporarily drawing native uranium-rich groundwater into the wells. In lower Pueblo Canyon, sustained but gradual uranium increases began in about 1980 and appear to be coincident with increased discharges of effluent from an upstream sanitary wastewater treatment

plant. Despite the trend upward, uranium concentrations in lower Pueblo Canyon regional groundwater remain low, about one-tenth the EPA standard.

INTRODUCTION

Los Alamos National Laboratory (LANL or the Laboratory) has long used uranium in its research programs, starting with the Manhattan Project in the early 1940s. Uranium has been released as liquid effluents and as solid waste into some of the canyons draining the Laboratory (Becker 1992, DOE 1981). These discharges represent a potential contamination concern for the water resources of the area. Much of the water carried by the canyons is lost to the subsurface rather than flowing offsite. Groundwater is the major source of drinking water in the region.

This report documents a survey of Los Alamos waters for uranium derived from the Laboratory. For many decades LANL has discharged isotopically modified (non-natural) uranium, which may be traceable. Discerning the origin of uranium in groundwater can be difficult, as there are several potential sources. In addition to the possible Laboratory sources, widespread elevated uranium concentrations of natural origin are present in groundwater east of the Laboratory within the Rio Grande valley (McQuillan and Montes 1998).

The Laboratory's Environmental Surveillance Program initiated this study in 1994 to evaluate the origin of uranium present in groundwater in the Los Alamos region. Using analytical "fingerprinting" techniques (thermal ionization mass spectrometry [TIMS]), the naturally occurring and anthropogenic forms of uranium were measured in surface water and groundwater samples. The uranium concentrations were evaluated relative to US Environmental Protection Agency (EPA; EPA 2000) drinking water standards. To add further perspective, we compiled historical uranium monitoring results for the region and compared against the TIMS results.

GEOLOGIC AND HYDROLOGIC SETTING

Geology and Land Use

The Laboratory is located in northern New Mexico on the Pajarito Plateau, which extends eastward from the Jemez Mountains (Figures 1 and 2). The Rio Grande borders the 43-square-mile Laboratory on the east. The Pajarito Plateau is capped by Bandelier Tuff, an ignimbrite erupted from the Jemez Mountains volcanic center (Griggs 1964). The tuff is approximately 800 ft thick in the western portion of the plateau and thins down to zero but can be as thick as 260 ft above the Rio Grande (Figure 3).

The Pajarito Plateau is situated within the western portion of the Española Basin, a north-south-oriented graben and a segment of the Rio Grande Rift. The Basin is bounded by Precambrian uplifts on the east and west and filled with sediments eroded from the adjacent mountains and with basalt from the Cerros del Rios volcanic field. The oldest rocks discussed here are poorly consolidated sands, clays, and gravels of the Santa Fe Group, which are rift-filling sediments deposited from about 20 to 7 Ma (million years before present) (Goff et al. 1989). Most groundwater used in the region is withdrawn from the upper 1,000 ft of the basin-fill deposits. Some volcanic ash beds and Miocene sandstones and conglomerates contain uranium deposits (McQuillan and Montes 1998, Chenowith 1979). Studies at LANL note that uranium is ubiquitous in the Bandelier Tuff of the Pajarito Plateau (Longmire et al. 1995). Erosion by intermittent streams has cut deep east-to-west-oriented canyons into the Pajarito Plateau, which slopes from the Jemez Mountains caldera downward toward the Rio Grande and the Rio Chama. Most Laboratory and community development is on the fingerlike mesa tops.

Climate and Surface Water

Precipitation in the Los Alamos area averages about 19 in./yr and increases with elevation. The plateau is semiarid, with ponderosa pine forest at higher elevations changing to piñon-juniper woodland as elevation decreases. The canyons contain riparian vegetation and small streams.

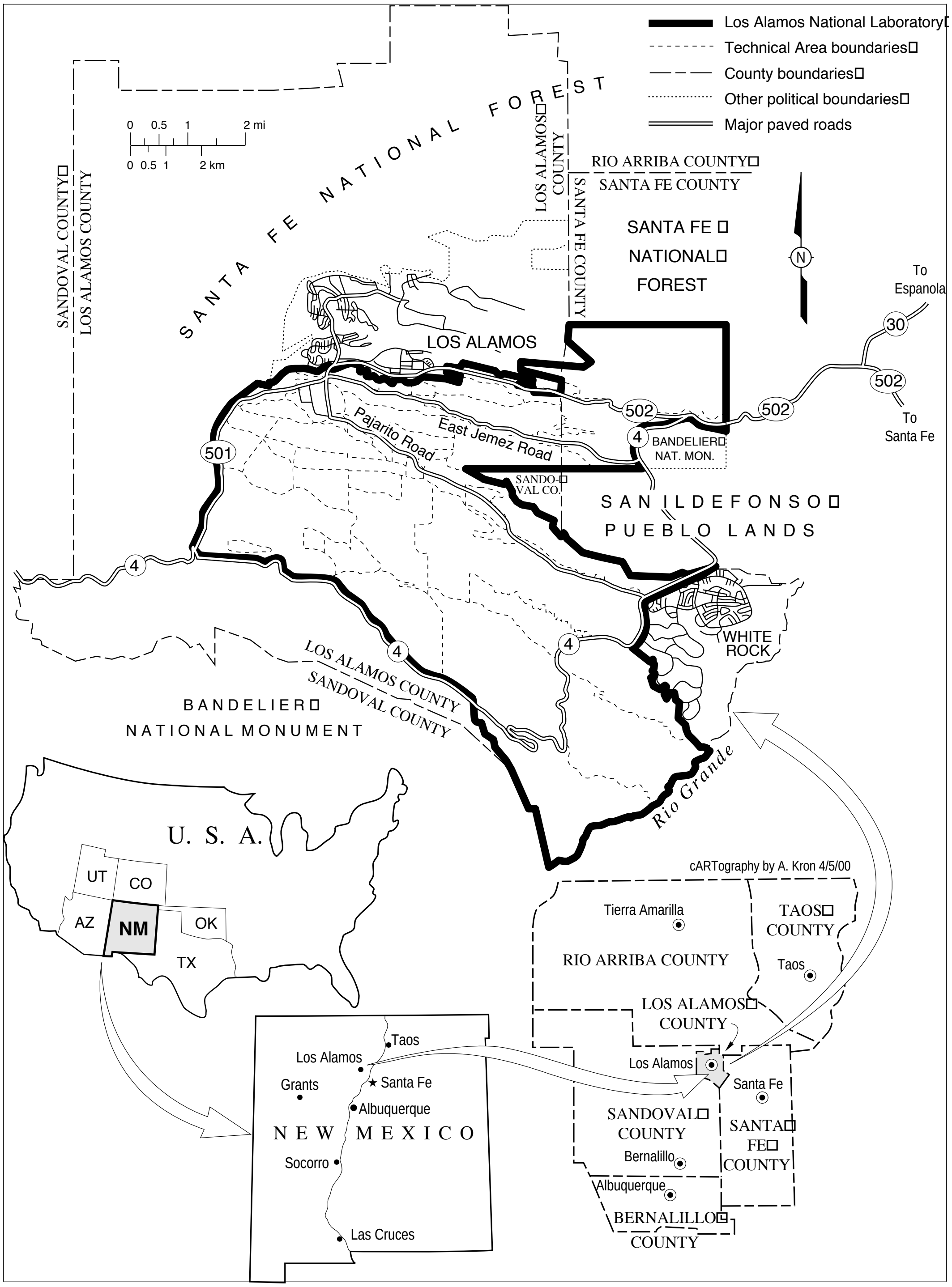


Figure 1. Location of Los Alamos National Laboratory.

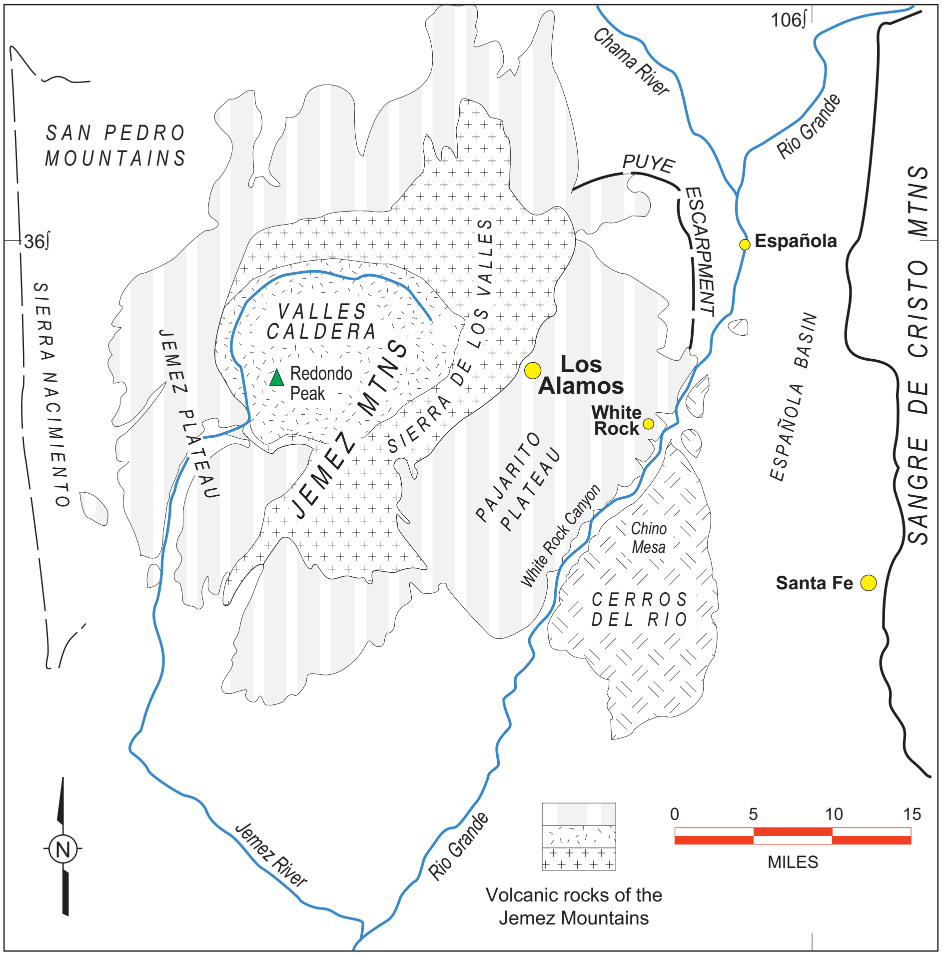


Figure 2. Location map showing geologic and topographic features near Los Alamos and the Pajarito Plateau (Barr et al. 2001).

Surface water in the Los Alamos area occurs primarily as short-lived or intermittent reaches of streams. Perennial springs on the flanks of the Jemez Mountains supply base flow into upper reaches of some canyons, but the volume is insufficient to maintain surface flows across the Laboratory site before they are depleted by evaporation, transpiration, and infiltration. Runoff in some canyons, resulting from large thunderstorms or heavy snowmelt, reaches the Rio Grande several times a year. Effluents from sanitary sewage, industrial waste-treatment plants, and cooling-tower blowdown enter some canyons at rates sufficient to maintain surface flows for varying distances.

Groundwater

The hydrogeological setting of the Española Basin is typical of other semiarid basins in the Western US. Groundwater is recharged in rocks of the mountains and adjacent alluvial-fan deposits and flows toward the Rio Grande, the master stream of the Basin. A fraction of the groundwater discharges directly to the Rio Grande or is withdrawn by evapotranspiration or wells, and the remainder exits the basin by underflow to the south. Beneath the Pajarito Plateau, the movement of water in the regional aquifer is from the recharge area in the west to the east and southeast, where a part is discharged through seeps and

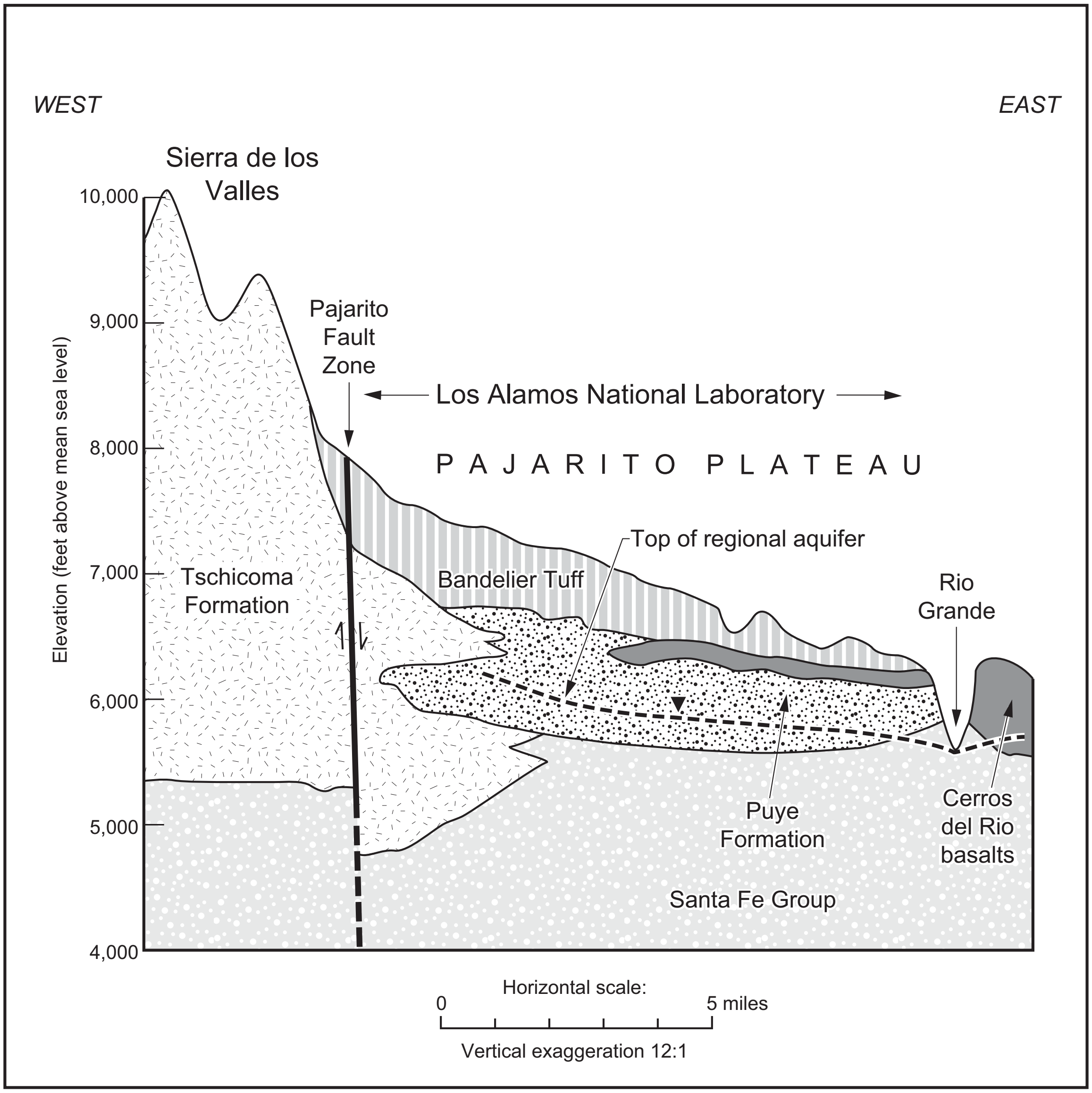


Figure 3. Generalized geologic cross section across the Pajarito Plateau (Barr et al. 2001).

about 20 springs into White Rock Canyon on the Rio Grande (Figure 4). The 11-mile reach of the Rio Grande in White Rock Canyon from Otowi to Frijoles Canyon receives an estimated 2,200 ac-ft annual discharge from springs (Purtymun 1966).

Groundwater in the Los Alamos area occurs in three primary modes, two of which are perched (Figure 5). Perched groundwater is a body of groundwater above a less permeable layer that is separated from an underlying main body of groundwater by an unsaturated zone. The modes of groundwater occurrence are (1) perched water in shallow alluvium in canyons, (2) perched water mainly beneath the larger canyons at depths from about 100 to 700 ft, and (3) the regional aquifer. These types of groundwater are described in more detail below.

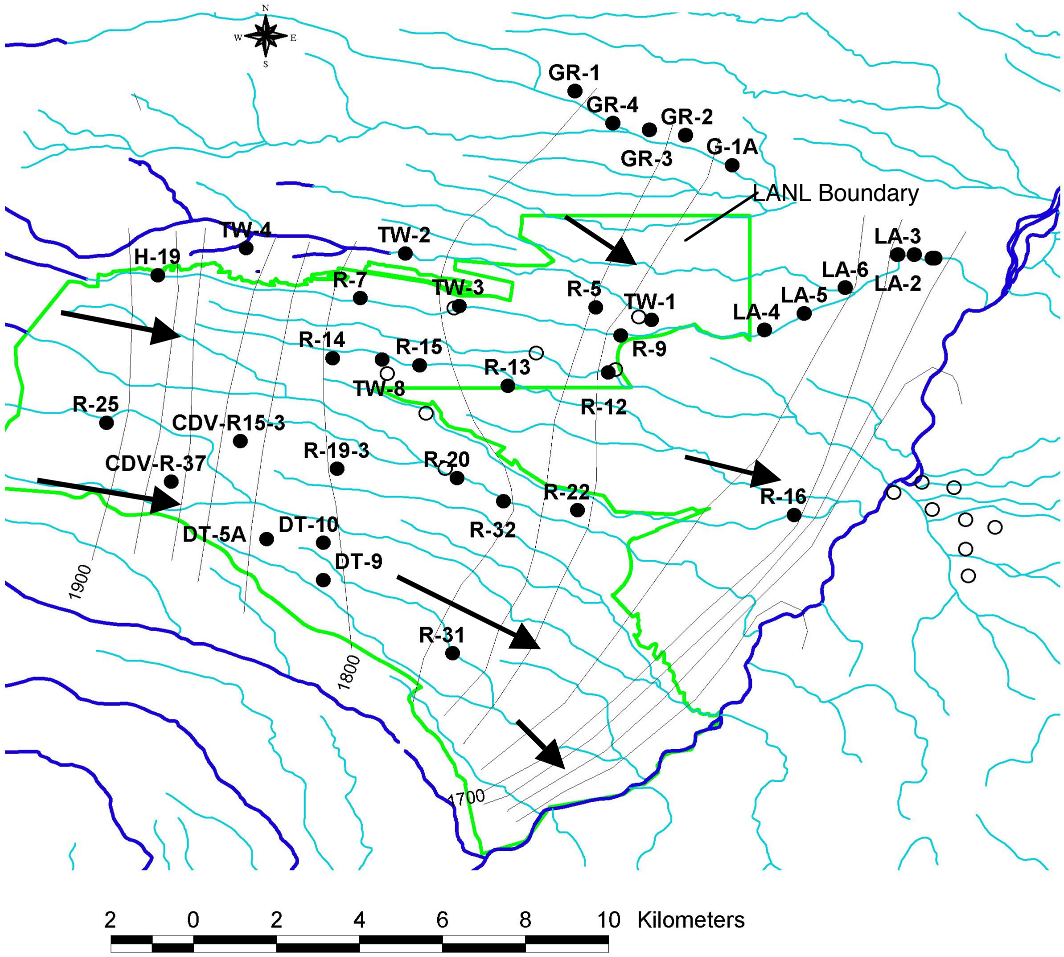


Figure 4. Generalized water-level contours on top of the regional aquifer near Los Alamos National Laboratory (modified from Nylander et al. 2003). Water level contour interval is 200 m. Arrows signify general horizontal directions of groundwater flow.

Streams and erosion have filled some parts of canyon bottoms with alluvium ranging up to as much as 100 ft in thickness. Stream runoff percolates through the alluvium until downward flow is impeded by less permeable layers of tuff. This creates shallow bodies of perched groundwater within the alluvium. As water in the alluvium moves down the canyon, evapotranspiration and infiltration into underlying rocks deplete it. The chemical quality of shallow groundwater in most wet canyons shows Laboratory-derived chemicals from discharges.

In the northeastern corner of Los Alamos County, perched groundwater at intermediate depths occurs beneath portions of Pueblo, Los Alamos, and Sandia Canyons within thick unsaturated rock underlying the alluvium. The intermediate perched groundwater occurs within the lower part of the Bandelier Tuff and within the underlying conglomerates and basalt (Figure 5). The perched groundwater has been found

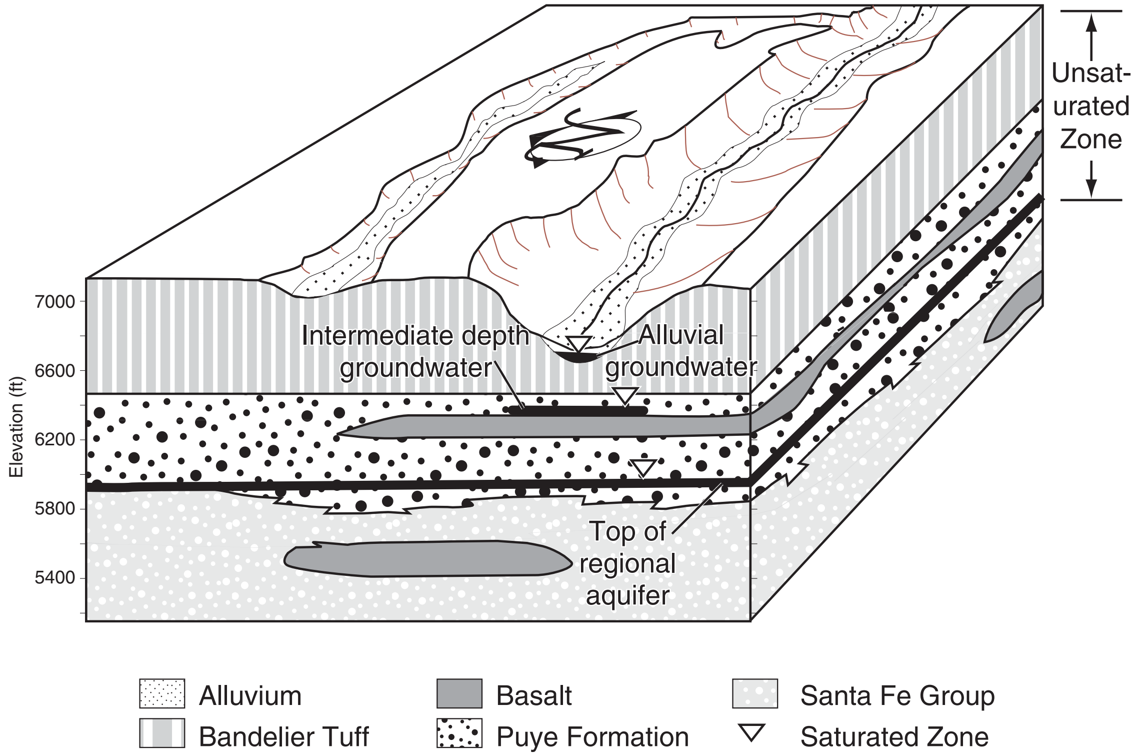


Figure 5. Illustration of geologic and hydrologic relationships in the Los Alamos area, showing the three modes of groundwater occurrence (Barr et al. 2001).

in this area at depths ranging from about 120 ft in Pueblo Canyon to about 450 ft in Sandia Canyon. These intermediate-depth groundwater bodies are formed in part by recharge from the overlying perched alluvial groundwater. The intermediate-depth groundwater shows radioactive and inorganic contamination from Laboratory operations (ESP 1999, Longmire 2002a, b).

Perched water also occurs within the Bandelier Tuff and Puye Formation at the western Laboratory boundary near the Jemez Mountains at a depth of 700 ft. The source of this perched water may be infiltration from streams discharging from the mouths of canyons along the mountain front and underflow of recharge from the Jemez Mountains (Stone et al. 2002).

The regional aquifer underlying the Los Alamos area occurs at a depth of 1,200 ft along the western edge of the plateau and 600 ft along the eastern edge. It is the only aquifer in the area capable of serving as a municipal water supply. The surface of the aquifer rises westward from the Rio Grande within the Santa Fe Group. The aquifer rises into the lower part of the Puye Formation beneath the central and western part of the plateau. Depth to the regional aquifer is 1,000 ft to 1,200 ft beneath the mesa tops in the central part of the plateau. The regional aquifer is separated from the shallow and intermediate-depth perched waters by hundreds of feet of unsaturated rock and sediments with generally low (<10%) moisture content. Despite the significant thickness of largely unsaturated rock, tracer studies have shown some hydraulic communication between the surface and the deep regional aquifer within the past 50 years (Rogers 1998, Longmire 2002a).

BACKGROUND INFORMATION ON URANIUM

Uranium occurs naturally in the earth's soils and rocks. Once thought as rare, uranium is now considered about as abundant as molybdenum or arsenic (LANL 2003). The three most abundant isotopes of natural uranium are uranium-234, uranium-235, and uranium-238, and all are radioactive. Naturally occurring uranium nominally contains 99.2745 percent by weight uranium-238, 0.720 percent by weight uranium-235, and 0.0055 percent by weight uranium-234 (Audi and Wapstra 1995). Each of these isotopes has a long radioactive half-life. Uranium-234 has a half-life of 245 thousand years. Uranium-235 has a half-life of 704 million years. Uranium-238 has a half-life of 4.5 billion years.

To identify Laboratory-derived uranium in this study we will focus on precisely measuring the relative proportions of uranium-235 and uranium-238 in water samples to determine if different than in natural uranium. LANL historically has used isotopically modified uranium in its research. A significant departure in the atom (mass) ratio of uranium-238 to uranium-235 from natural will signify the likely presence of Laboratory-derived uranium. The atom ratio of uranium-238 to uranium-235 in naturally occurring uranium is a constant 137.88.

Much of the uranium used at LANL has more (enriched) or less (depleted) uranium-235 abundance than natural uranium. Uranium-235 is isolated (enriched) from the other uranium isotopes by diffusion and electromagnetic processes. The abundance of uranium-235 in highly enriched uranium may be on the order of 90 percent, while the uranium-235 abundance in highly depleted uranium may be on the order of 0.25 percent. Enriched uranium may have an atom ratio of uranium-238 to uranium-235 lower than 0.06, while in depleted uranium it may exceed 500.

An additional check for LANL-derived uranium occurs if we identify the presence of the isotope uranium-236 in our water samples. The uranium-236 isotope generally does not occur in nature and its presence indicates an anthropogenic (i.e., LANL) origin. The uranium-236 isotope is formed through exposure to a neutron source, such as a reactor (Efurd et al. 1993). The Laboratory has used and discharged natural uranium, particularly 1943 through 1953; however, early records are lacking to describe the amount of natural uranium discharged (Becker 1991). Laboratory-derived natural uranium is only distinguishable from "background" or "native" uranium by looking for anomalous concentration patterns.

Criteria for Determining Detections of Enriched Uranium, Depleted Uranium, and Uranium-236

In evaluating whether the $^{238}U/^{235}U$ atom ratio is statistically different than natural, we consider both the measured atom ratio and the uncertainty associated with the analysis. These uncertainties represent a one standard deviation (one sigma) propagated uncertainty. "It is virtually unanimously accepted that an analyte should be reported as present when it is measured at a concentration three-sigma or more above the corresponding blank" (Keith 1991). Therefore, we report detections of enriched or depleted uranium as $^{238}U/^{235}U$ atom ratios three sigma (three standard deviations) or more from natural indicate Laboratory impacts. Ratios significantly much less than 137.88 typically indicate the admixture of an enriched uranium-235 component with natural uranium; ratios greater than 137.88 include a depleted uranium-235 component.

Because uranium-236 generally does not exist in nature, any sample showing detectable levels of the isotope suggests Laboratory impacts. We assume uranium-236 to be detected when the $^{236}U/^{235}U$ atom ratio is statistically distinct from zero, or three sigma or more away from zero.

The decision of whether or not an analytical detection has occurred is a choice that includes the statistical confidence level that one is willing to accept in evaluating samples (Rogers 2001, Keith 1991). The question of detection of Laboratory-derived uranium is not absolute but is an application of a statistical model to a set of samples. For example, the choice of a three-sigma criterion, above which an analytical result is called a detection, carries with it a risk of a certain number of false positives (cases in which the result for a sample containing no analyte will be called a detection) and false negatives (cases in which the presence of an analyte will be overlooked).

After the initial round of sampling, groundwater stations indicating non-natural uranium were re-sampled. These are single-point analyses often without backup or duplication to assure sample integrity. Single particle contamination can not be ruled out, thus the need for multiple sampling to assure real differences from natural isotopic abundances.

For this study, general confirmation of a preliminary finding of LANL-derived uranium occurred when

(a) it was verified with repeated sampling,

(b) it was consistent with other sample results in the area, for example along the same watercourse, or

(c) the initial atom ratios were highly skewed from natural, by more than twenty sigma.

If the preliminary result is not confirmed through this review, it is treated as a possible detection of Laboratory-derived uranium. Because the surface water quality is more highly variable with time than groundwater, the preliminary results usually cannot be similarly confirmed.

Environmental Uranium Standards

Several regulatory agencies have published standards or guidelines that specify acceptable levels of uranium in waters. The calculated limits vary as a function of many factors including the exposure scenario in which the public is assumed to ingest water that contains uranium, the acceptable risk levels, and the understanding of health response upon exposure. Some standards are presented as a concentration limit (mass of total uranium per liter—for example, micrograms per liter or μg/L) and others are presented as a radioactivity limit (number of “decay events” over time of a specific uranium isotope per liter—for example, picocuries per liter or pCi/L).

Uranium in the public water supply is governed by EPA regulations contained in 40 CFR Parts 9, 141, and 142 (EPA 2000). The EPA Maximum Contaminant Level (MCL) for total uranium concentration is 30 μg/L. This MCL will be the primary standard against which we compare our groundwater sampling results.

The current New Mexico Water Quality Control Commission (NMWQCC) uranium standard for groundwater is 5,000 μg/L (NMWQCC 2000). While the New Mexico Environment Department has proposed lowering the groundwater standard to 7 μg/L, the NMWQCC has not completed review of the proposed standard.

The US Department of Energy (DOE) establishes derived concentration guides (DCGs) for radionuclide activities permissible for waters open to public access (uncontrolled) areas near DOE facilities. The concentration guides for water are based on DOE’s radiation protection standard (or public dose limit) of 100 mrem/yr and are determined assuming a water ingestion rate of 2 L/day. For DOE drinking water systems, the public dose limit is lowered to 4 mrem/yr and is equal to the EPA standard contained in 40 CFR 141 for humanmade beta- and photon-emitting radionuclides (EPA 1996). The concentration guides represent the smallest estimated concentrations for a radionuclide that, taken continuously for 50 years, will result in an annual dose equal to the public dose limit in the 50th year of exposure. These concentrations guides are based on recommendations of the International Commission on Radiological Protection Publication 23 (ICRP undated). The concentration guides for water are applicable to effluent discharges and impacted surface and groundwater but not to soil moisture.

The most recent DOE DCGs for uranium were finalized in 1990 by DOE Order 5400.5 (DOE 1990). The DCGs for the principal uranium isotopes are as follows:

Isotope	DCG	Public Exposure Mechanism
Uranium-234	500 pCi/L 24 pCi/L	Ingestion of Environmental Waters (for example, swimming) Ingestion from DOE Drinking Water System
Uranium-235	600 pCi/L 20 pCi/L	Ingestion of Environmental Waters (for example, swimming) Ingestion from DOE Drinking Water System
Uranium-238	600 pCi/L 20 pCi/L	Ingestion of Environmental Waters (for example, swimming) Ingestion from DOE Drinking Water System

The surface water within the Laboratory is not a source of municipal, industrial, or irrigation water, though wildlife does use the waters. Activities of radionuclides in surface water samples are compared with either the DOE DCGs (ingestion of environmental waters) or the NMWQCC (2000) stream standards. The stream standards reference the New Mexico radiation protection activity levels, which are, in general, two orders of magnitude greater than the DOE DCGs for public dose, so we discuss only the DCGs here.

URANIUM USE AT LOS ALAMOS

The Laboratory was established in 1943 as a part of the Manhattan Project effort to construct the first atomic weapons. From those early days, much of the research activities at the Laboratory centered on the fissionable isotopes uranium-235 and plutonium-239 because they would make up the cores of the first nuclear weapons. Except for small experimental quantities, these materials were shipped to Los Alamos from other industrial plants across the country (DOE 1997).

Because of the scarcity of uranium-235 and its strategic importance, it is likely that relatively small quantities of enriched uranium were discharged to the environment at the Laboratory. Large quantities of depleted uranium, uranium left over from the enrichment process, have been expended in explosives testing at Laboratory firing sites (Becker 1992). This results in dispersion of depleted uranium particles over a large distance away from the firing pad. Most of the firing site activity has been conducted in Pajarito, Potrillo, Water, and Ancho Canyons. The firing sites occupy at least half of the total land area represented by the Laboratory.

There have been three principal radioactive liquid effluent discharge areas at Los Alamos. Two of these were into Acid and DP Canyons, small tributaries within the Pueblo/Los Alamos Canyon watershed near the northern boundary of the Laboratory (DOE 1981). The other discharge is in Mortandad Canyon within the central portion of the Laboratory; it is the site of the only current radioactive discharge at the Laboratory.

Discharge information for uranium isotopes is incomplete for early periods at the Laboratory. Several decades of relatively complete records exist for uranium-234 activities, however, and these were assembled for 1979–1998 from yearly LANL Environmental Surveillance Reports. In order to better gauge the quality of effluent discharges, we converted the uranium-234 activities to equivalent total uranium concentrations, assuming predominantly natural isotopic composition. Table 1 shows estimated total uranium discharges from 1979 for Technical Area (TA) 50 and TA-21. Discharges into Mortandad

Table 1. Liquid Releases of Total Uranium into Mortandad Canyon (TA-50) and DP/Los Alamos Canyon (TA-21) for 1979−1998.

	TA-50 Effluent Discharges			TA-21 Effluent Discharges		
	Total Effluent Volume	Estimated Mean Total Uranium Annual Conc. Ranges[a]		Total Effluent Volume	Estimate Mean Total Uranium Annual Concentration Ranges[a]	
	($L \times 10^7$)	Low End (μg/L)	High End (μg/L)	($L \times 10^7$)	Low End (μg/L)	High End (μg/L)
1979		6	13		20	40
1980	5.28	13	25	0.2	321	642
1981	5.53	25	50	0.44	306	613
1982	3.98	44	88	0.37	350	700
1983	2.87	31	61	0.36	627	1255
1984	3.5	161	321	0.42	1255	2510
1985	2.86	22	44	0.15	161	321
1986	3	117	233	Plant ceased operation in 1986		
1987	2.66	88	175			
1988	2.93	39	79			
1989	2.28	32	64			
1990	2.1	5	10			
1991	2.19	4	9			
1992	1.99	4	7			
1993	NA					
1994	2.08	8	19			
1995	1.76	21	42			
1996	1.65	17	34			
1997	1.75	7	14			
1998	2.32	7	15			

[a]The estimated total uranium concentrations were calculated from published mean annual uranium-234 activity discharge records. We first converted the uranium-234 activities to mass concentrations by dividing the activities by the specific activity of uranium-234, i.e., 6,230 pCi/μg. Then we calculated likely total uranium concentrations by multiplying the uranium-234 mass concentrations by a proportionality factor equal to its 0.0055% abundance in natural uranium, i.e., 18,182 μg total uranium/μg uranium-234. This represents the "high end" estimate above and assumes that uranium-234 is in secular equilibrium with uranium-238. To account for possible disequilibrium in the effluent between uranium-234 and uranium-238, we include a "low end" estimate that assumes uranium-234 activity twice that of uranium-238.

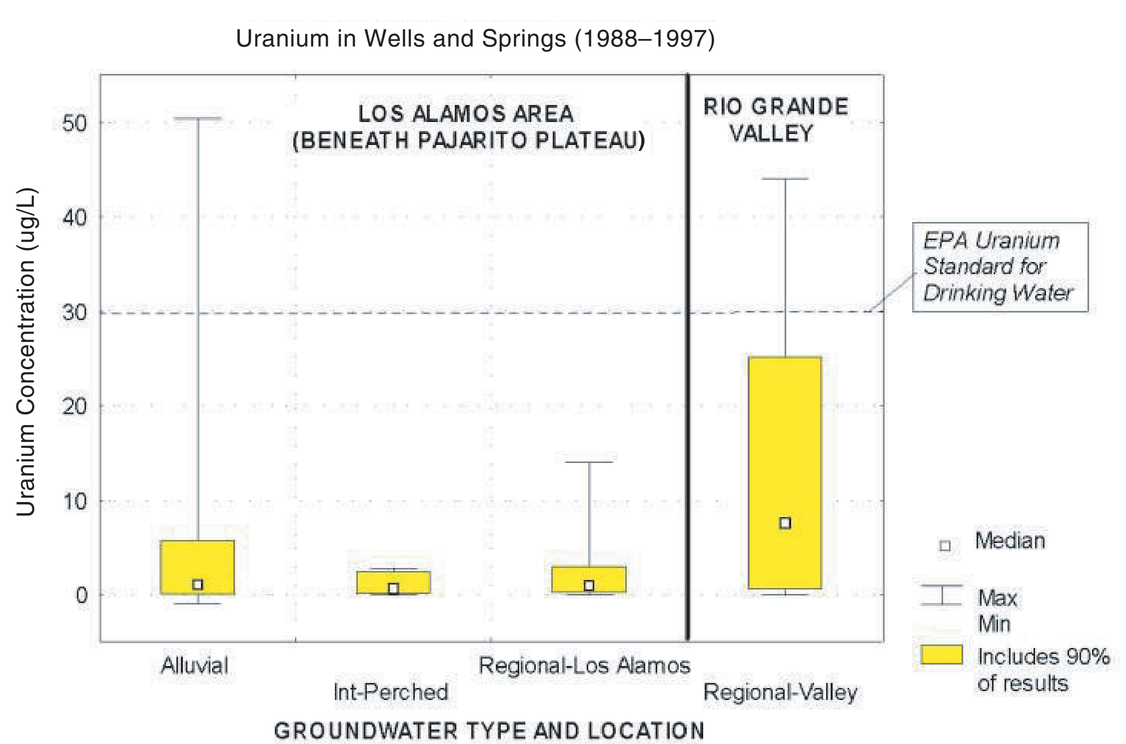
Canyon (TA-50) contained a flow-weighted average total uranium concentration up to approximately 80 μg/L, while discharges into DP/Los Alamos Canyon (TA-21) averaged up to approximately 1,100 μg/L. The estimated total uranium concentrations are up to 3 and 37 times greater, respectively, than the EPA uranium standard for drinking water systems of 30 μg/L (EPA 2000). Uranium concentrations in the effluents have substantially declined since the 1980s.

SUMMARY OF HISTORICAL MONITORING RESULTS

Since the early 1960s, the Laboratory's Environmental Surveillance Program has annually tested waters in the Los Alamos area for a wide variety of chemicals and radioactivity. This information provides a substantial data set to describe the variability of total uranium concentrations in the region's groundwaters.

To complement the TIMS data, we compiled all available Environmental Surveillance data for uranium concentrations in groundwater in the Los Alamos region for the 10-year period 1988 through 1997. The historical monitoring results are summarized in Figure 6. Location and groundwater zones separate the data into four groups:

- shallow alluvial groundwater on the Pajarito Plateau,



Alluvial = Shallow alluvial groundwater on the Pajarito Plateau; Int-Perched = Intermediate-depth perched groundwater on the Pajarito Plateau; Regional-Los Alamos = Regional aquifer wells and springs within the Pajarito Plateau; Regional-Valley = Regional aquifer wells and springs in San Ildefonso area (San Ildefonso Pueblo and White Rock Canyon springs east of river).

Figure 6. Box plot of total uranium concentrations for groundwater in the Los Alamos region, 1988 through 1997 data. Data from LANL annual Environmental Surveillance Reports.

- intermediate-depth perched groundwater on the Pajarito Plateau,
- regional aquifer springs and wells on the Pajarito Plateau, and
- regional aquifer springs and wells within the Rio Grande Valley, including those on San Ildefonso Pueblo lands and White Rock Canyon springs east of the Rio Grande.

Total uranium concentrations in the regional aquifer within the San Ildefonso area (valley) are higher than those found in the aquifer beneath the Pajarito Plateau. This reflects natural uranium (McQuillan and Montes 1998). Median total uranium concentrations are 7.6 µg/L in valley stations and 1.0 µg/L in plateau stations. Median concentrations in all of the groundwater bodies sampled in the Los Alamos area are well under the EPA standard of 30 μg/L for drinking water systems, although a few percent of the shallow groundwater results are above the standard. Based on this review of the 10-year results, there is no indication of major impacts from Laboratory discharges on regional aquifer groundwater.

Total uranium concentrations in the Rio Grande below the Laboratory are statistically indistinguishable to those above (Kruskall Wallis non-parametric ANOVA, $p = 0.05$). Concentrations measured by the Laboratory's Environmental Surveillance Program (1988–1997) for the Rio Chama and Rio Grande are summarized in Figure 7. Stations upstream of the Laboratory include the Rio Chama at Chamita, Rio Grande at Embudo, and Rio Grande at Otowi. Uranium concentrations at these upstream stations are compared to the downstream station of Rio Grande below Cochiti Reservoir. Based on this review of the 10-year results, there is no indication of impacts to the Rio Grande surface water from Laboratory operations.

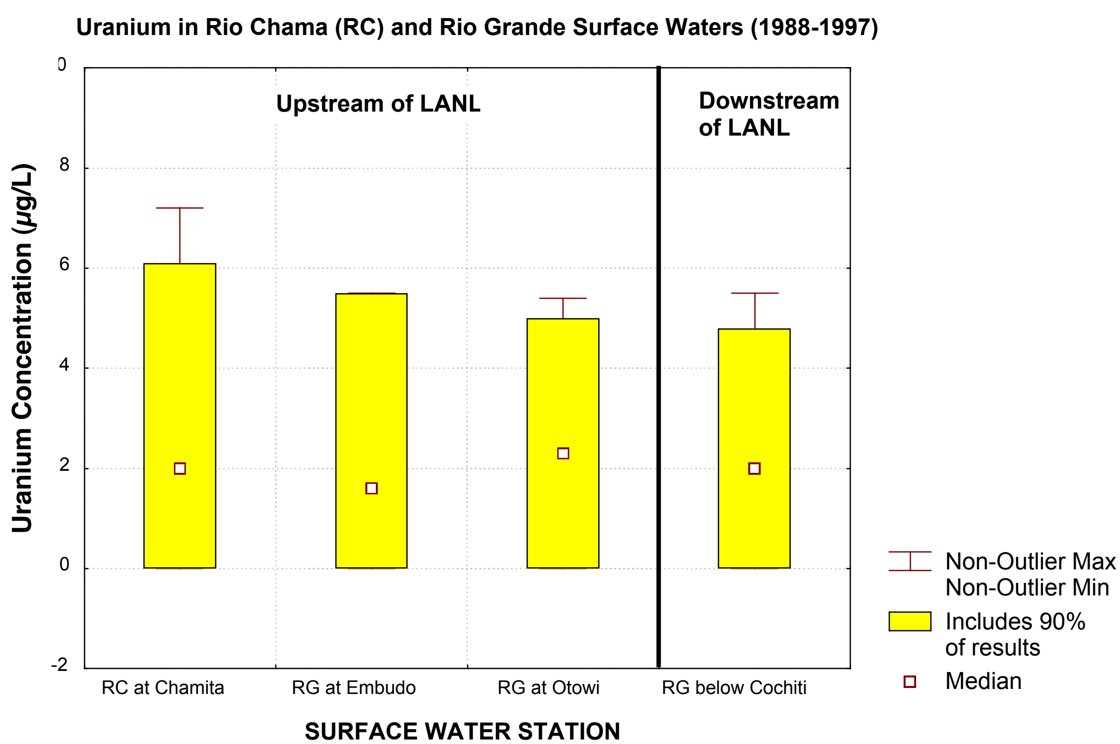


Figure 7. Box plot showing total uranium concentrations for surface water in the Rio Chama (RC) and Rio Grande (RG), 1988 through 1997. Data from LANL annual Environmental Surveillance Reports.

SAMPLING LOCATIONS AND METHODS

Samples of streams, springs, and wells were collected for this TIMS survey over a 5-year period, 1994–1999. Sample locations are shown in Figures 8–11. Sampling was conducted on the Laboratory and on adjacent lands, principally those controlled by Los Alamos County, San Ildefonso Pueblo, the US Forest Service, and Bandelier National Monument.

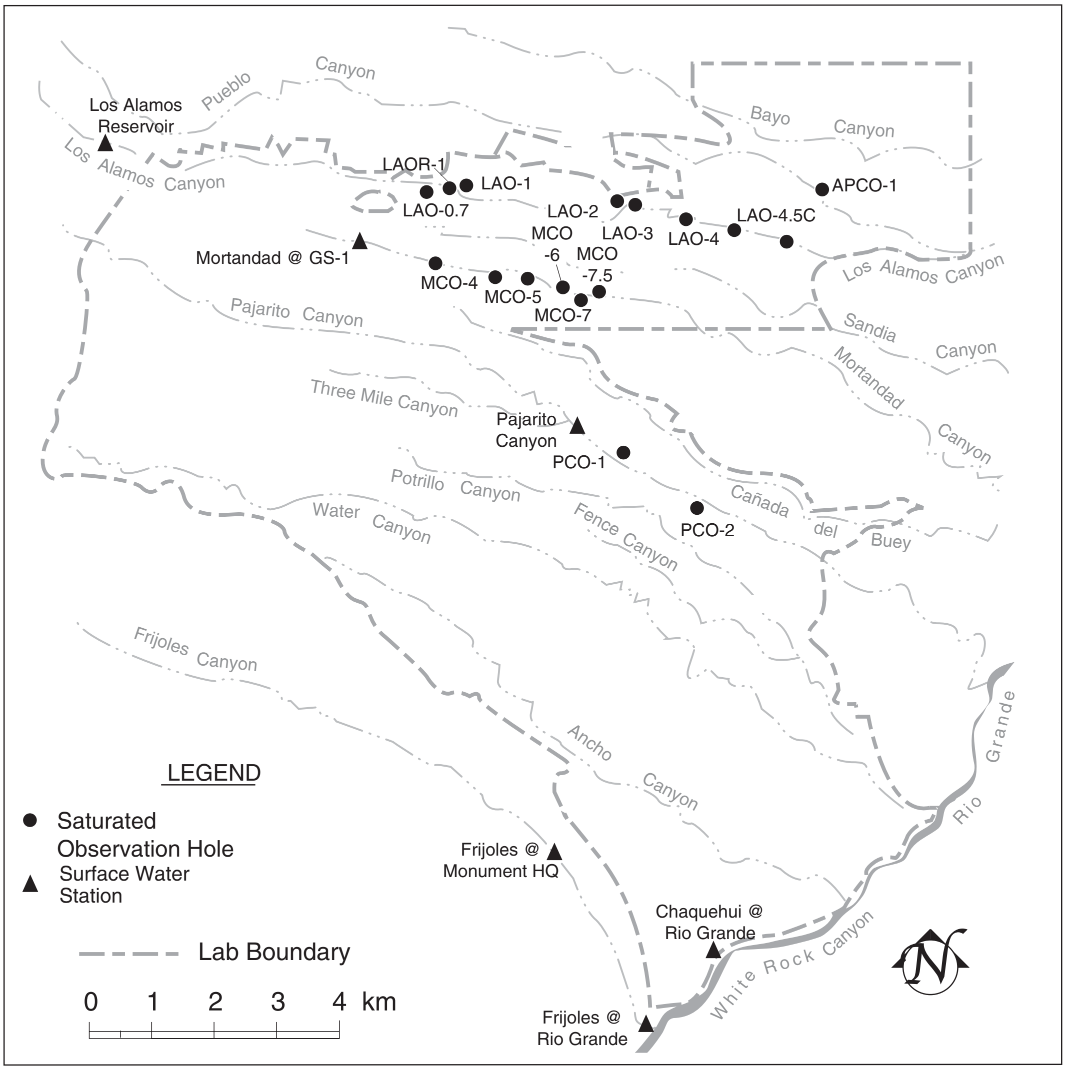


Figure 8. Surface water and alluvial groundwater sampling locations on and adjacent to Los Alamos National Laboratory.

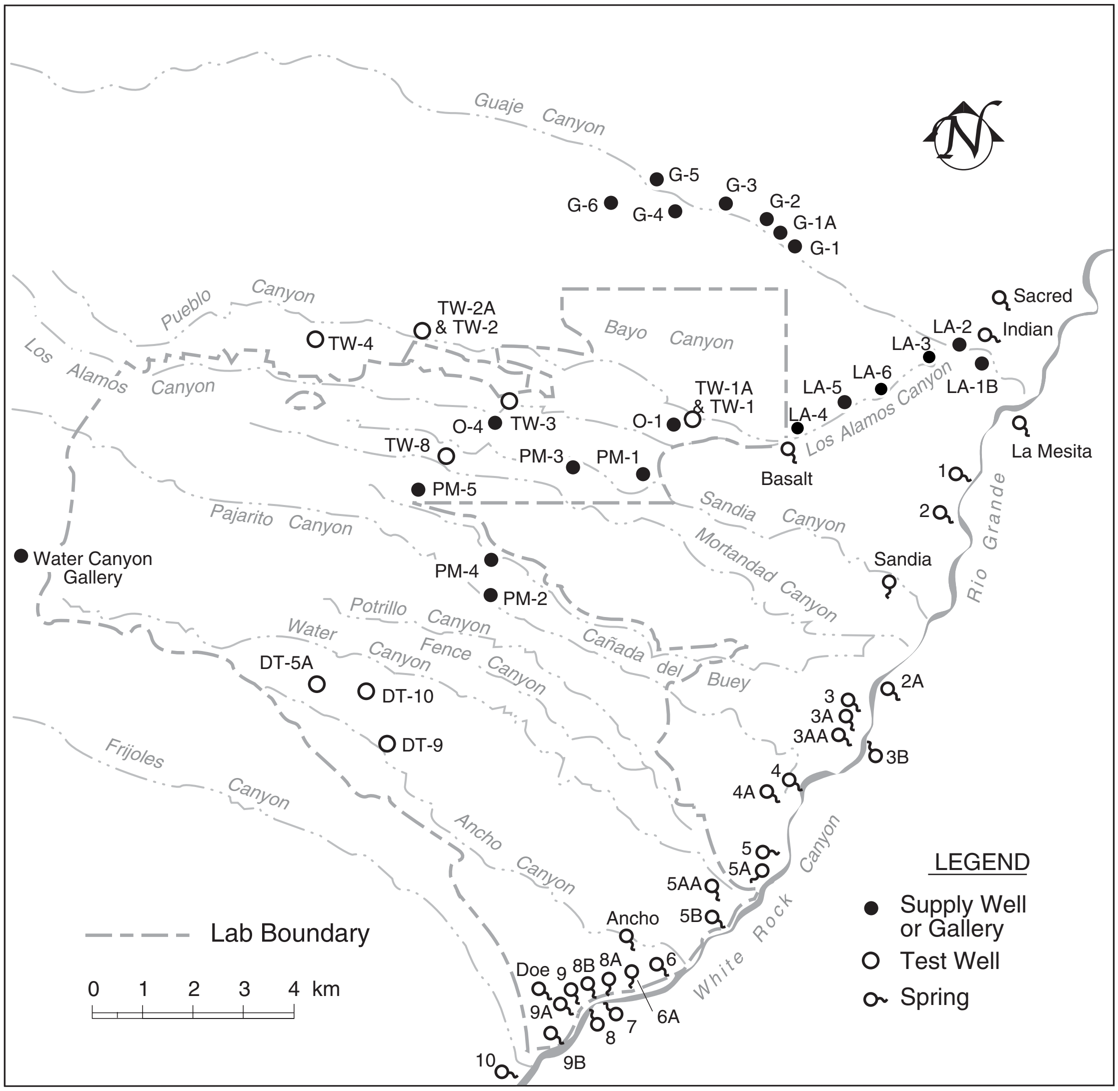


Figure 9. Springs, intermediate-depth wells, and regional aquifer wells sampled on and adjacent to Los Alamos National Laboratory.

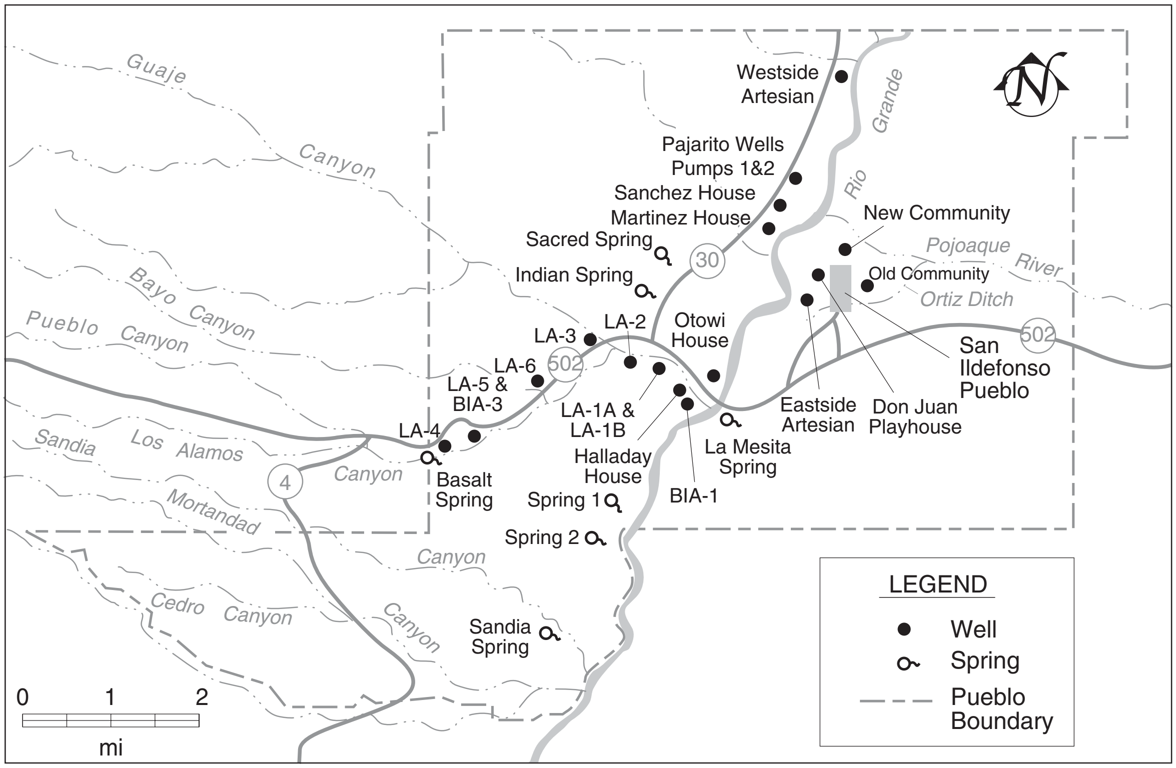


Figure 10. Springs and groundwater stations on or adjacent to San Ildefonso Pueblo lands.

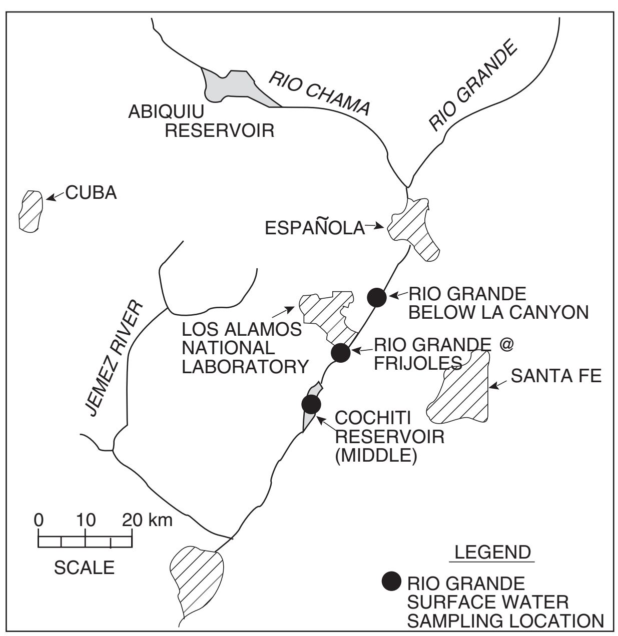


Figure 11. Rio Grande surface water sampling locations.

Owing to the generally dry nature of the site, limited surface water sampling was conducted. A total of 10 surface water stations were sampled, seven from sites on the Pajarito Plateau and the remainder from the Rio Grande downstream of the Laboratory.

A total of 64 groundwater stations were sampled. A grouping of the stations that were sampled follows:

- 6 Los Alamos municipal water supply wells,
- 11 San Ildefonso Pueblo water supply and irrigation wells,
- 7 regional aquifer test wells,
- 21 regional aquifer springs in or near White Rock Canyon,
- 15 shallow wells in canyon alluvium perched groundwater, and
- 4 perched groundwater test wells and springs.

Samples of streams and large springs were collected by hand dipping a sample bottle into the stream several times until the required volume was accumulated. The smaller springs were sampled by lowering tubing into the streamflow and either pumping the sample with a peristaltic pump or gravity-feeding the flow into sample containers.

Existing pumps were used to sample domestic, public supply, and irrigation wells. All samples were collected from the distribution system as near to the well as possible, before any treatment system, and not from a pressure tank. If the wells had not already been running at the time of sampling, they were purged. Each of the alluvial monitoring wells within the Laboratory was equipped with dedicated positive-displacement Teflon™ bladder pumps. Before alluvial wells were sampled, they were purged for 15 to 30 minutes. Water samples were collected at each well by pumping until water temperature, specific conductance, and pH were judged constant; a minimum of three well-bore volumes was pumped from all wells not in regular service.

All of the water samples collected from the first round of testing were submitted for analysis as whole (non-filtered) samples in order to conservatively evaluate the uranium concentrations, including both dissolved and particulate phases. If anthropogenic uranium was suggested in the initial analytical results, additional confirmatory sampling of the well or spring was performed. During the confirmatory sampling, some waters from low-volume springs were filtered before analysis, if it appeared likely the spring water may be picking up uranium from surface soils.

Samples were acidified to a pH <2 with ultrapure concentrated nitric acid within three hours of collection. The acid prevents the actinides from adhering to the container walls and therefore not bias the analytical results.

TIMS EXPERIMENTAL METHODS

Samples collected for this study were submitted to the Los Alamos Clean Chemistry and Mass Spectrometry Laboratory for TIMS analyses. All of the actinide activity levels and the atom ratios reported in this report were derived from the TIMS analyses. The procedures for TIMS analysis of uranium are described in detail in Efurd et al. (1993). The TIMS procedures are briefly summarized below.

TIMS sample preparation and mass spectrometry are both performed in class-100 clean areas specifically designed for ultra-low-level environmental actinide analyses. Waters are traced with precisely known amounts of reference standards, separated into elements by anion exchange chromatography, and electroplated on mass spectrometry filaments to produce an ionization source for TIMS analysis. The filament is then inserted into a thermal ionization mass spectrometer that measures the relative abundance of the isotopes of interest compared with the reference standards.

The TIMS procedure allows for the quantification of the isotopic composition of the uranium in the sample, for example, the number of atoms of the isotope uranium-235 and of the isotope uranium-238 in a gram of sample. The following uranium isotopes are determined: uranium-234, uranium-235, uranium-236, and uranium-238.

Quality Control

Thirteen samples were split at the mass spectrometry analytical laboratory and analyzed in duplicate. The relative percent difference (RPD) is a measure of the variability in the values produced by the analytical method. RPD was calculated for each pair of duplicate samples by the equation:

$$RPD = 100x\left|\frac{sample1 - sample2}{\left(\frac{sample1 + sample2}{2}\right)}\right|$$

where sample 1 and sample 2 are the concentrations or atom ratios in duplicate samples.

The RPD for total uranium concentrations ranged from 0.03 percent to 2.9 percent, and the median was 0.6 percent. For $^{234}U/^{235}U$ atom ratios, the RPD ranged from 0.01 percent to 9.6 percent, and the median was 1.7 percent. For $^{236}U/^{235}U$ atom ratios, the RPD ranged from 10 percent to 960 percent, and the median was 228 percent. Uranium-236 was not detected in any of these paired samples and this accounts for the large RPD. For $^{238}U/^{235}U$ atom ratios, the RPD ranged from 0.01 percent to 1.1 percent, and the median was 0.8 percent.

Twenty-nine duplicate water samples were collected in the field for total uranium concentration analyses and processed at different analytical laboratories. One set of samples was submitted to the Mass Spectrometry Laboratory and analyzed by TIMS. The duplicate sample set was submitted to LANL’s Environmental Chemistry Laboratory and analyzed by conventional uranium metal analytical methods (Inductively Coupled Plasma or ICP). The TIMS and ICP results show excellent comparability ($R^2 = 0.969$). The median RPD for the pairs of total uranium concentration measurements was 3.6 percent, and RPDs for individual data pairs ranged from 0.7 percent to 22 percent.

OVERVIEW OF TIMS ANALYTICAL RESULTS

A summary of the TIMS results is presented in Table 2. The table lists only those results that suggest a possible presence of LANL-derived uranium, and a conclusion whether that initial finding was confirmed with later testing and analysis. Complete TIMS uranium analyses of water samples are presented in the Appendix. Data for groundwater samples are shown in Table A-1 in the Appendix. The results are organized by mode of groundwater occurrence and by location. Surface water TIMS results are presented in Table A-2.

Table 2. Summary of Locations Shown to Possibly Contain LANL-derived Uranium.

Station	Indication of Uranium	LANL Uranium Confirmed?	Reason
Groundwater			
Pueblo Canyon Alluvial well APCO-1	EU	Yes	>20 sigma from natural.
Los Alamos Canyon Alluvial wells (LAOR-1,-2, -3,-4-5)	EU in all, U-236 in LAO-2	Yes	Pattern through drainage. >20 sigma EU in LAO-2.
Mortandad Canyon Alluvial wells (MCO-4, -5, -6)	EU in all, U-236 in all	Yes	Pattern through drainage. >20 sigma EU and U-236 in all wells.
Pajarito Canyon Alluvial Wells (PCO-1, -2)	DU in all, U-236 in PCO-2	Yes	Pattern through drainage.
Ancho Spring	DU	Yes	Detected in follow up sample. Not certain if in groundwater or in stream sediments.
O-4	EU	No	Not detected with 6 other TIMS measurements on samples from 2 other dates.
G-2	EU	No	Not detected with 1 other TIMS measurement on sample from 1 other date.
Sandia Spring	DU	No	Not detected with 6 other TIMS measurements on samples from 2 other dates
Spring 4A	DU	No	Not detected with 3 other TIMS measurements on samples from 2 other dates.
Spring 9	DU	No	Not detected with 1 other TIMS measurement on sample from 1 other date.
Water Canyon Gallery	EU	No	Not detected with 3 other TIMS measurements on sample from 1 other dates.
Surface Water			
Mortandad at GS-1	EU, U-236	Yes	Pattern through drainage.
Cochiti Middle	DU	No	Only the single sample taken.
Frijoles Creek at Rio Grande	DU	No	Not detected with 1 other TIMS measurement on sample from 1 other date.

Note: EU = Enriched Uranium; DU = Depleted Uranium; U-236 = Uranium-236.

Table 2. Summary of Locations Shown to Possibly Contain LANL-derived Uranium (Cont.).

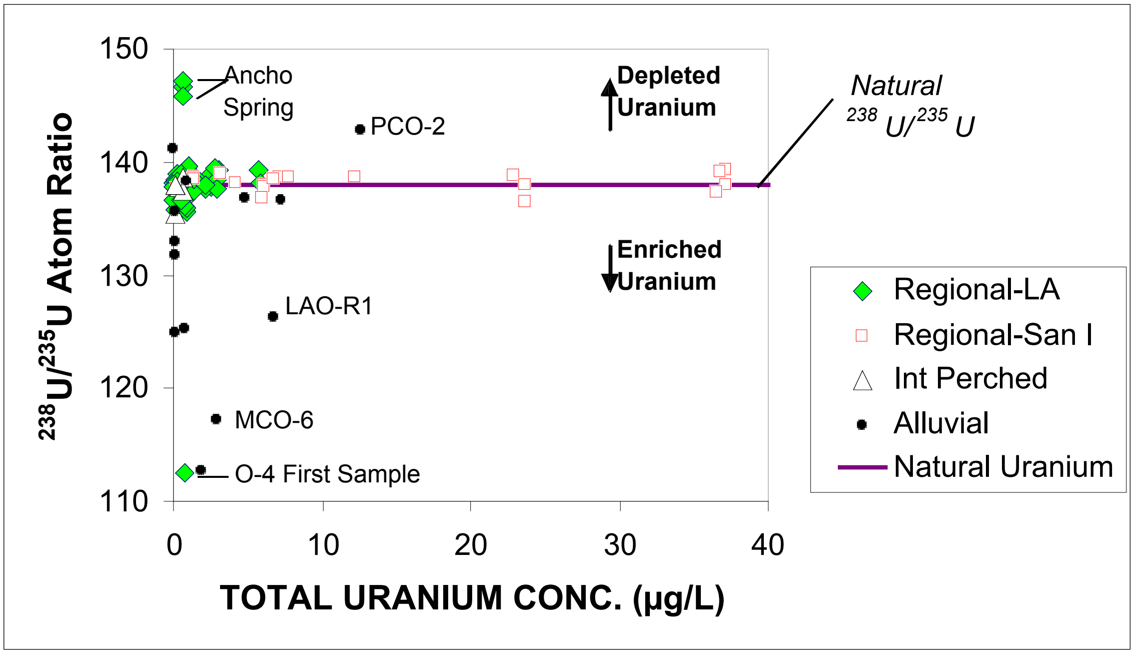
Station	Total U in TIMS Sample (µg/L)	Percentage of EPA Drinking Water Standard	Percentage of Total U-235 in Sample Attributable to LANL
Groundwater			
Pueblo Canyon Alluvial well APCO-1	0.6	3	9
Los Alamos Canyon Alluvial wells (LAOR-1,-2, -3,-4,-5)	0.09–6.7	0.3–22	2–44
Mortandad Canyon Alluvial wells (MCO-4, -5, -6)	1.4–2.9	5–10	15–39
Pajarito Canyon Alluvial Wells (PCO-1, -2)	0.04–12.7	0.1–42	0.8–1.3
Ancho Spring	0.65	2	2
O-4	0.7	2	0.5*
G-2	0.9	3	1*
Sandia Spring	1.0	3	0.5
Spring 4A	1.0	3	0.5
Spring 9	2.8	9	0.1
Water Canyon Gallery	0.16	0.5	0.1*
Surface Water			
Mortandad at GS-1	0.38	1	8
Cochiti Middle	0.09	0.3	0.9
Frijoles Creek at Rio Grande	0.08	0.3	0.6

Note: U-235 = Uranium-235.

*Does not include suspect value from initial round of sampling (see discussion in "Locations with Enriched Uranium" section).

TIMS results show Laboratory-derived uranium is evident in the alluvial groundwater of Pueblo, Los Alamos, Mortandad, and Pajarito Canyons. The LANL uranium in Pajarito Canyon is likely from past firing site releases, while all the other canyons reflect current or past liquid effluent discharges. The Laboratory-derived uranium is usually barely perceptible within a few miles downstream because of dilution from infiltration of natural streamflow and chemical interaction with the soils. Although some initial results indicated the presence of enriched uranium in deeper groundwaters, we were unable to verify any of these indications through repeat testing of these wells and springs. Depleted uranium was confirmed to be present in samples taken from Ancho Spring, but we are uncertain if the depleted uranium is actually in the groundwater or rather is associated with the stream sediments through which the spring issues.

At stations showing a LANL influence, the net effect on uranium concentrations is typically slight. The average uranium concentration amongst shallow groundwaters was 3 μg/L, compared to the EPA standard for drinking water systems of 30 μg/L. Figures 12 and 13 show the relationships between the total uranium concentrations and the $^{238}U/^{235}U$ and $^{236}U/^{235}U$ atom ratios. LANL-derived uranium is not evident above a uranium concentration of about 13 μg/L.



Regional-LA = Regional aquifer in Los Alamos area, including test wells, Los Alamos water supply wells, and regional aquifer springs along White Rock Canyon; Regional-San I = Regional aquifer within Rio Grande Valley, including San Ildefonso area; Int Perched = Intermediate-depth perched groundwater; Alluvial = Groundwater in canyon alluvium.

Figure 12. Relationship between $^{238}U/^{235}U$ atom ratios and total uranium concentrations in groundwater samples.

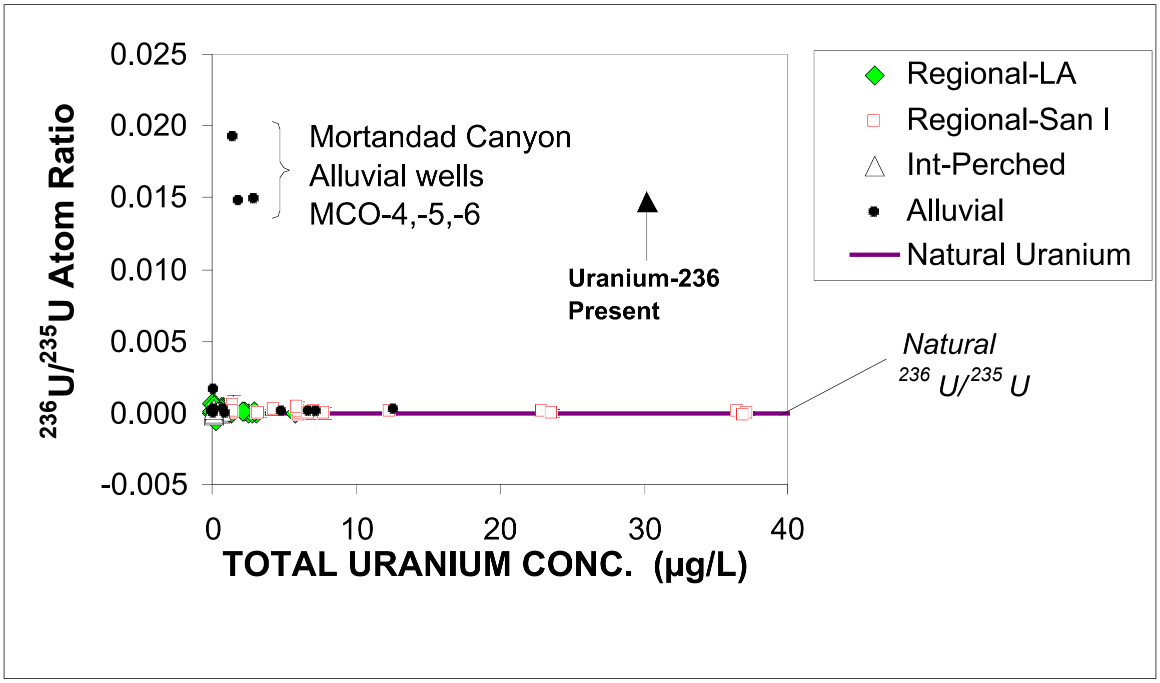


Figure 13. Relationship between $^{236}U/^{235}U$ atom ratios and total uranium concentrations in groundwater samples.

Uranium Concentrations

Uranium concentrations in groundwater ranged from 0.01 to 37 μg/L. The concentrations are the sum of the uranium-234, uranium-235, uranium-236, and uranium-238 concentrations. Of the 93 samples, two were greater than the EPA standard for uranium in drinking water of 30 μg/L (EPA 2000). All of the high concentrations are found in San Ildefonso Pueblo wells located within the Rio Grande valley. Previous studies by the New Mexico Environment Department showed elevated concentrations (maximum 920 μg/L) of naturally occurring uranium to be common in shallow groundwater throughout the Pojoaque Valley area east of San Ildefonso Pueblo (McQuillan and Montes 1998).

The highest total uranium concentration measured in the Rio Grande by TIMS was 1.9 μg/L. During the 1990s, LANL's surveillance program collected an additional 60 Rio Grande surface water samples downstream of LANL and analyzed them using conventional analytical methods. Median total uranium concentration in the 1990s was 1.7 μg/L, and the highest was 6.7 μg/L, approximately one-fourth the drinking water standard.

On the Pajarito Plateau, there were no results greater than the EPA standard. The highest concentration found in Pajarito Plateau TIMS samples was 12.7 μg/L in shallow well PCO-2 in Pajarito Canyon.

Uranium Activities

The radioactivity of a given mass of uranium is dependent on the contribution from the isotopes with different half-lives. Total uranium activities in these groundwater samples ranged from 0.01 to 28 pCi/L. The isotopes uranium-234 and uranium-238 account for greater than 97 percent of the total U activity, with uranium-235 providing less than 3 percent. The radioactive decay of uranium is the primary source of gross alpha activity in the regional groundwater.

The uranium activity ratio of uranium-234 to uranium-238 varies over a relatively large range from 1.1 to 2.9. Uranium activity ratios >1.0 indicate uranium-234 is in excess of uranium-238, which results in greater gross alpha activity for a given mass of uranium. The disequilibrium is due to natural processes, as previously discussed. Where the deeper regional aquifer samples show the most disequilibrium, several shallow alluvial groundwater samples show near-equilibrium conditions. This distinction may be helpful in regional hydrologic characterization studies.

Uranium Atom Ratios

The preponderance (91%) of the water stations contained uranium of natural composition. Of those samples indicated to contain a component of anthropogenic uranium, most were enriched in uranium-235. Groundwater samples showing anthropogenic uranium were limited to the Pajarito Plateau. Detections of anthropogenic uranium in groundwater were confirmed only in the shallow perched groundwater—none in the intermediate-depth, perched, or regional aquifers. The atom ratio of $^{238}U/^{235}U$ ranged from 76.5 to 147.1 in the groundwater samples, compared to 137.88 in naturally occurring uranium. Three surface water samples appear to contain anthropogenic uranium; two of these (Cochiti Middle and Frijoles at Rio Grande) were taken from or near the Rio Grande. The $^{238}U/^{235}U$ atom ratio in surface water samples ranged from 126.3 to 141.3.

The samples that appear to have non-natural isotopic signatures based on atom ratio measurements for $^{236}U/^{235}U$ and $^{238}U/^{235}U$ are of two main categories:

- natural uranium admixed with a depleted uranium-235 component (found in the southeast quadrant of the Laboratory) and

- natural uranium admixed with an enriched uranium-235 component (found in the northeast quadrant of the Laboratory).

In approximately one-third of the water samples with depleted or enriched uranium-235, we also detected uranium-236, the artificially created isotope. The highest levels of uranium-236 were found in the surface water and shallow groundwaters of Mortandad Canyon and represent a unique signature for those waters. For each uranium-236 detection, we also detected either depleted or enriched uranium-235.

These general findings are illustrated in scatter plots, which compare the measured $^{238}U/^{235}U$ and $^{236}U/^{235}U$ atom ratios (± 3 sigma uncertainty) against those of natural uranium (Figures 14–19). The measurement uncertainty for each result is displayed with error bars. If the error bars do not overlap (cross) the natural uranium values, we assume a possible detection of Laboratory-derived uranium. Groundwater depth and location group the results. The samples with the greatest isotopic departure from natural uranium are highlighted in the plots.

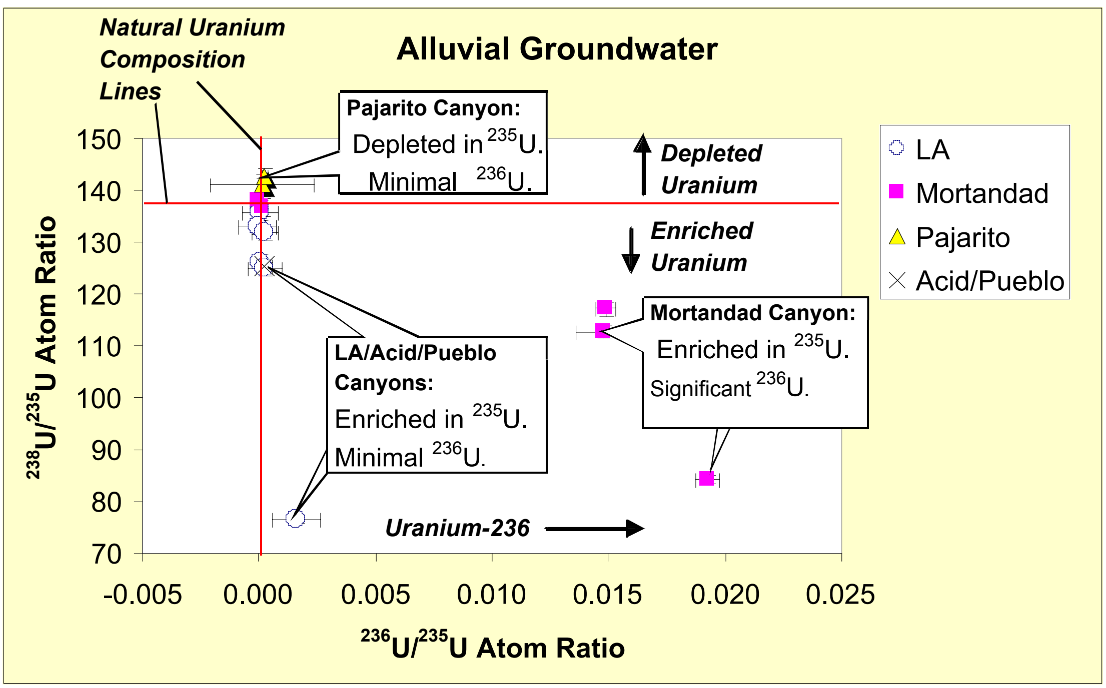


Figure 14. Uranium isotopic composition of alluvial groundwater in various canyons on the Pajarito Plateau. Error bars show the 3-sigma uncertainties (99% confidence interval). Laboratory-derived uranium is indicated if the error bars do not cross the natural uranium composition lines ($^{238}U/^{235}U = 137.88$ and $^{236}U/^{235}U = 0.0$). Samples containing depleted uranium plot above the horizontal line. Samples containing enriched uranium plot below the horizontal line. Samples containing uranium-236 plot to the right of the vertical line.

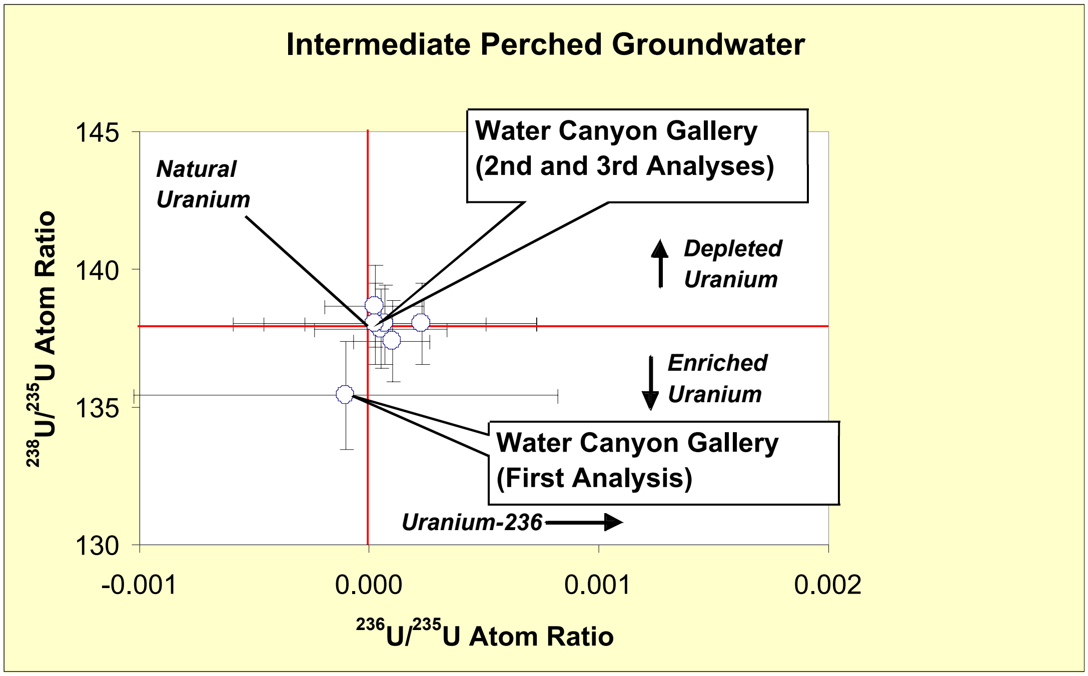


Figure 15. Uranium isotopic composition of intermediate-depth perched groundwater on the Pajarito Plateau.

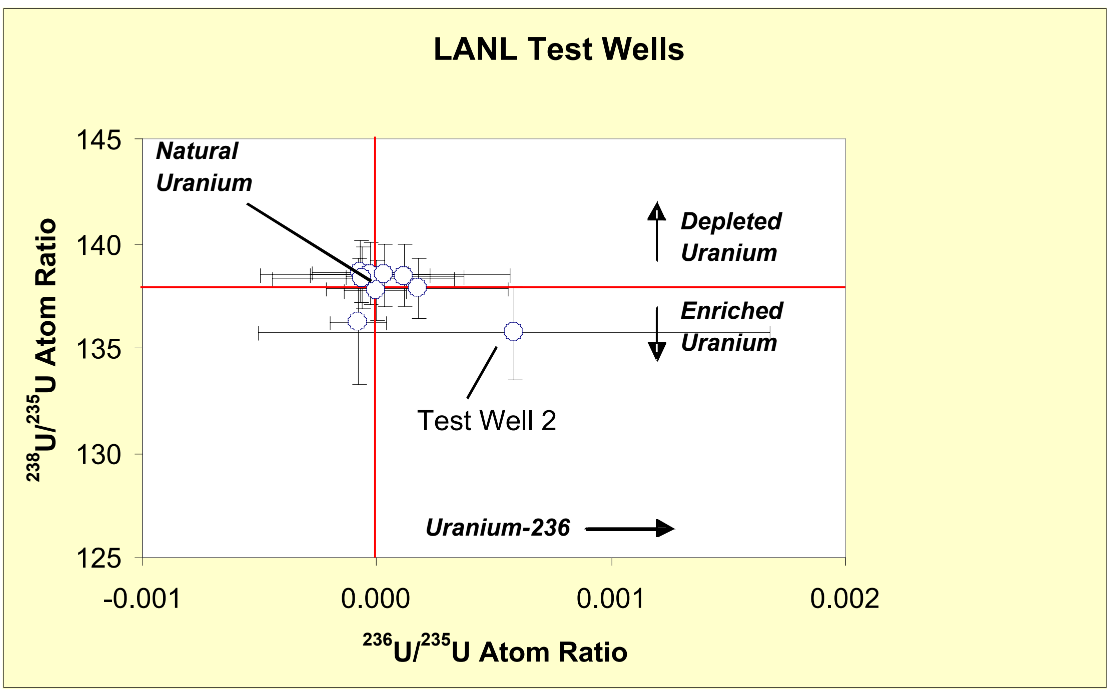


Figure 16. Uranium isotopic composition of regional groundwater from Los Alamos National Laboratory test wells. Error bars show 3-sigma uncertainties (99% confidence interval).

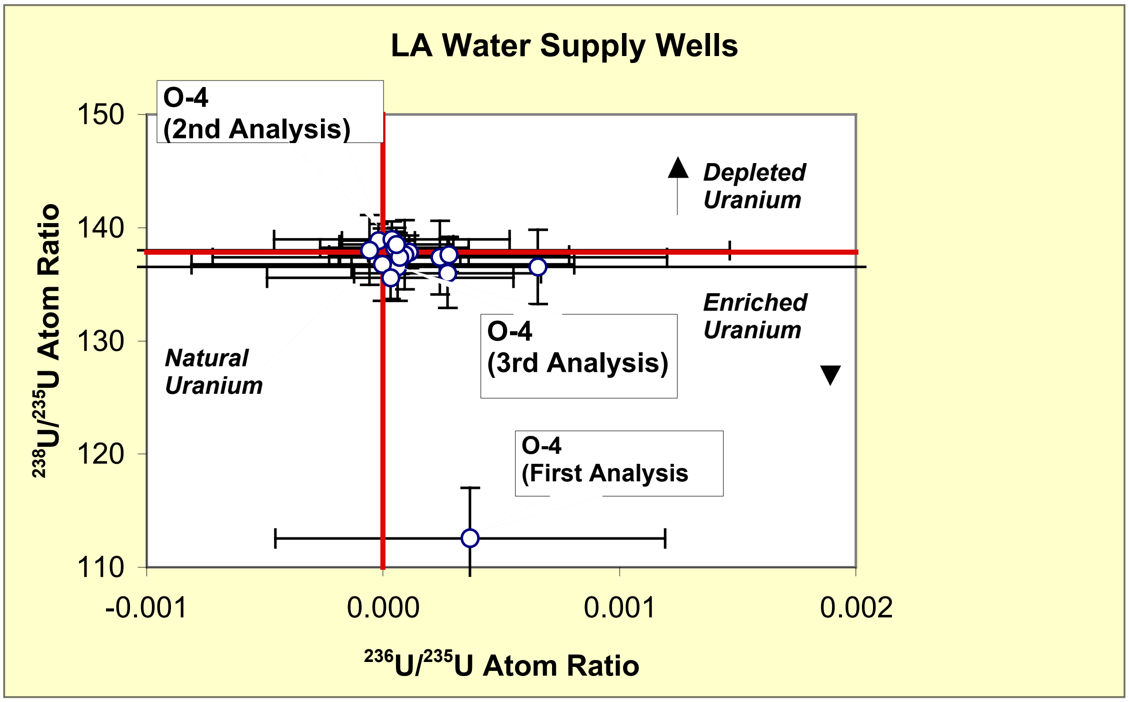


Figure 17. Uranium isotopic composition of regional groundwater from Los Alamos County water supply wells. Error bars show the 3-sigma uncertainties (99% confidence interval).

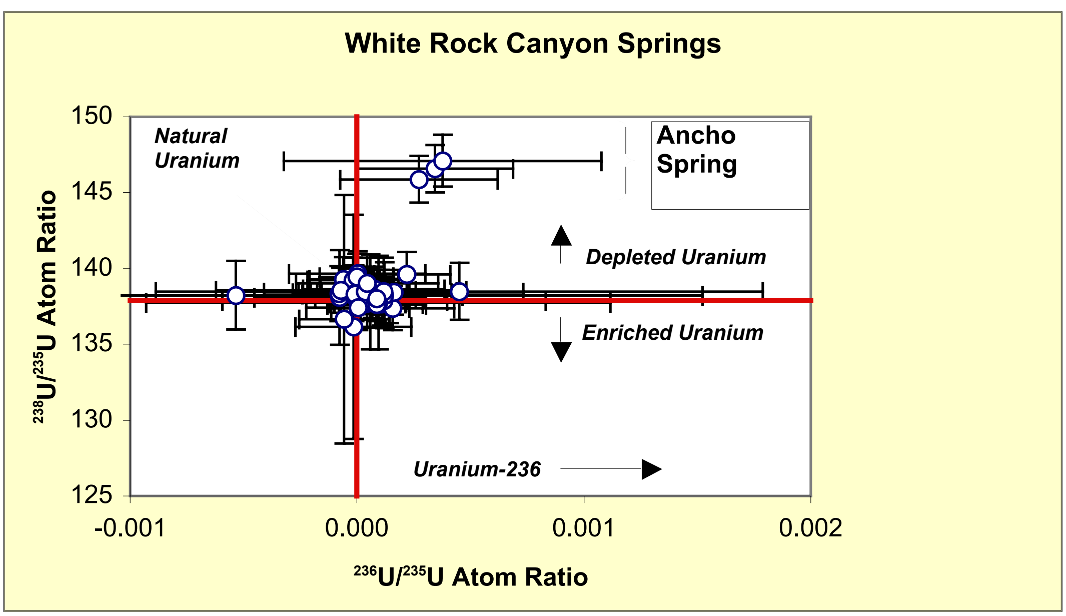


Figure 18. Uranium isotopic composition of groundwater from White Rock Canyon springs. Error bars show the 3-sigma uncertainties (99% confidence interval).

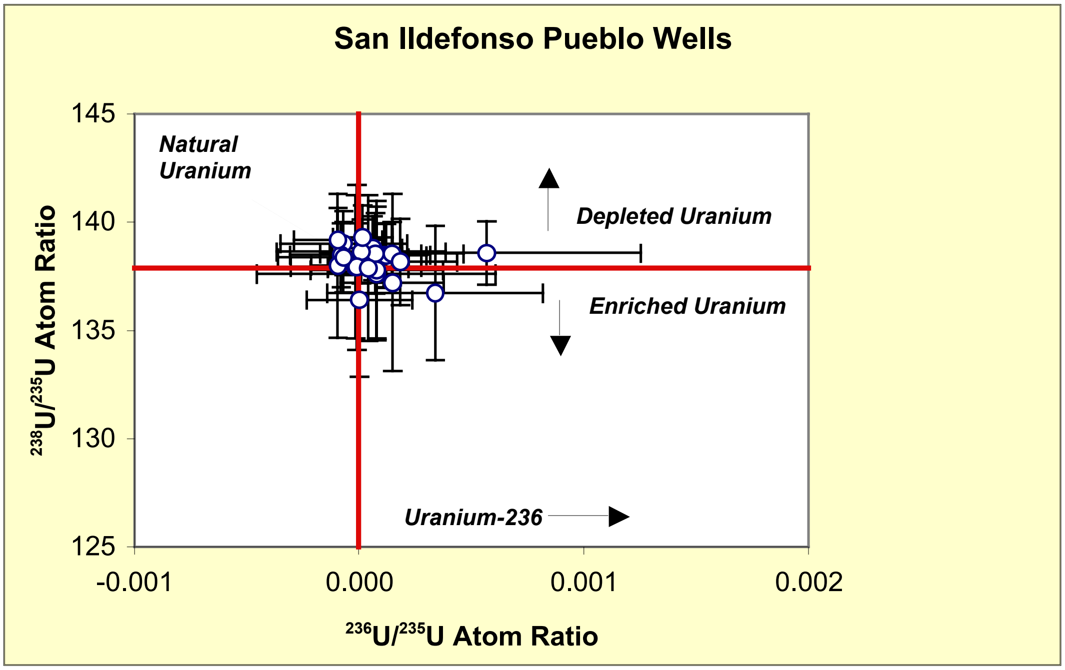


Figure 19. Uranium isotopic composition of groundwater from San Ildefonso Pueblo wells. Error bars show the 3-sigma uncertainties (99% confidence interval).

Locations with Depleted Uranium

Assuming 3 standard deviations from natural uranium isotopic composition as significant, waters at the following stations appear to contain a depleted uranium-235 component:

- Ancho Spring (regional aquifer),
- alluvial wells PCO-1 and PCO-2 in Pajarito Canyon,
- Frijoles Creek at the Rio Grande, and
- Cochiti Reservoir (middle).

We are not certain whether the depleted uranium in the Ancho Spring samples is actually in the groundwater feeding the spring or if the groundwater is picking up depleted uranium from contaminated stream sediments that cover the surface soils through which the spring issues. The presence of depleted uranium in sediments within the Ancho Canyon drainage at State Road (SR) 4 has been documented (Gallaher and Efurd 2002). The depleted uranium indicated at wells PCO-1 and PCO-2 may be attributable to historical firing site operations conducted near TA-18 (ER 1998).

The indication of depleted uranium in water collected from middle Cochiti Reservoir is different than other results available for the area, which all indicate the predominance of natural uranium. Two additional surface water samples from the Rio Grande show natural isotopic composition; one of these samples (Rio Grande below Los Alamos Canyon) was collected on the same date as the Cochiti Reservoir (middle) sample. Ten bed sediment samples collected from the reservoir bottom show natural uranium composition (Gallaher et al. 1999). Analyses of Cochiti Reservoir bottom-feeding fish collected in 1993 and 1994 similarly showed no evidence of anthropogenic uranium (Fresquez and Armstrong 1996).

Although depleted uranium was indicated in this single water sample from middle Cochiti Reservoir, these companion results indicate minimal overall impact to the reservoir.

Depleted uranium also was suggested in single samples from the following stations, but not confirmed with subsequent analyses: Sandia Spring, Spring 4A, and Spring 9. We hypothesize the depleted uranium measured at these sites and in Frijoles Creek is derived from airborne deposition of small quantities of depleted uranium on surface soils from LANL firing sites, as discussed further below.

Locations with Enriched Uranium

Groundwaters at the following stations appear to contain enriched uranium-235:

- Pueblo Canyon alluvial well APCO-1;
- Los Alamos Canyon alluvial wells LAO-1, LAOR-1, LAO-2, LAO-3, LAO-4, and LAO-4.5; and
- Mortandad Canyon surface water station GS-1 and alluvial wells MCO-4, MCO-5, and MCO-6.

The most enriched samples (approaching ~200 sigma from natural) were found in shallow wells in Los Alamos Canyon below the intersection with DP Canyon, probably showing the effects of TA-21 effluent discharges, and in shallow wells in Mortandad Canyon below the TA-50 Radioactive Liquid Waste Treatment Facility (RLWTF).

In addition, enriched uranium was measured in single samples from the following stations, but not confirmed in repeat samplings: Water supply well G-2 in Guaje Canyon; supply well O-4 in Los Alamos Canyon; and Water Canyon Gallery, a spring box on the flanks of the Jemez Mountains previously used for irrigation. Each of these possible detections were from samples collected in April and May 1994, and results from this time period appear to be systematically biased toward showing enrichment with the $^{238}U/^{235}U$ atom ratio. In 12 of 14 (86 percent) stations with repeat testing, the most isotopically enriched results were from the April and May 1994 sampling period. Each of these possible detections of enriched uranium in the supply wells is suspect and discounted. The initial result from the Water Canyon gallery is further suspect because the gallery is hydraulically upgradient and more than 1 km from Laboratory sources. For completeness, however, the results from the April and May 1994 samples are included in Table A-1, and uranium histories for those sites are reviewed in detail below.

ESTIMATING PROPORTION OF LABORATORY-DERIVED URANIUM

Following the method originally described by Efurd et al. (1993), we estimate the amount of depleted or enriched uranium that is present in each water sample. The analysis assumes a simple two-component system. Samples with a $^{238}U/^{235}U$ atom ratio greater than natural uranium are assumed to be an admixture of natural uranium and depleted uranium, while samples with low ratios are assumed to contain natural uranium and enriched uranium. We assume that the depleted uranium released by the Laboratory contains 0.2 percent uranium-235 ($^{238}U/^{235}U$ atom ratio of ~500) and the enriched uranium released by the Laboratory contains 95 percent uranium-235 ($^{238}U/^{235}U$ atom ratio of ~0.06). The estimates for Mortandad Canyon samples are less certain because of the unknown anthropogenic end-member.

Estimates are made using the following relationship:

(N238/N235)obs = {(N238/N235)dep or enr} {F} + {(N238/N235)nat} {1-F}, where (N238/N235)obs is the $^{238}U/^{235}U$ atom ratio measured in the sample, {(N238/N235)dep or enr} is the atom ratio in the depleted or enriched uranium, and {(N238/N235)nat} is the $^{238}U/^{235}U$ atom ratio in naturally occurring uranium. {F} is the fraction of depleted or enriched uranium in the sample and {1-F} is the fraction of the sample that is naturally occurring. This equation can be solved to provide an estimate of the amount of depleted or enriched uranium present in the samples.

Table 3 reports the estimated percentage of uranium present in each water sample attributable to Laboratory-derived uranium. In both Mortandad and Los Alamos Canyons the proportions of Laboratory uranium were near 40 percent in shallow groundwater below the major effluent sources, but decline to less than 5 percent downstream.

URANIUM HISTORIES AT SPECIFIC LOCATIONS WITH ANOMALOUS ISOTOPIC SIGNATURES

In the following sections, these general TIMS results are discussed in context with historical environmental monitoring data of the past decades. Here we narrow our focus to those locations (a) where the TIMS results suggest a LANL impact and (b) where uranium effluent discharges are known to have occurred.

Acid and Pueblo Canyons

The original disposal site for liquid wastes generated by the Manhattan Project was Acid Canyon, a small tributary of Pueblo Canyon. From 1943 to 1951, Acid Canyon received untreated radioactive industrial effluent from the TA-1 research activities. A treatment plant was completed at TA-45 in 1951 and discharged treated effluents that contained residual radionuclides into Acid Canyon from 1951 to 1964.

Based on TIMS atom ratio data, enriched uranium has been released into the Acid Canyon and Pueblo Canyon drainages. Enriched uranium has been measured in sediment collected at Acid Weir near the TA-45 discharge point (Gallaher and Efurd 2002) and in shallow groundwater within lower Pueblo Canyon at well APCO-1. Enriched uranium comprised 6 percent and 9 percent of the total ^{235}U at these respective sites. Table 4 summarizes the TIMS results for APCO-1. Anthropogenic uranium was not identified in the deeper groundwater zones beneath Pueblo Canyon—the intermediate-depth perched groundwater or the regional aquifer—at the 99 percent (3-sigma) confidence level. However, at Test Well 2, a regional aquifer well located in middle Pueblo Canyon, the measured $^{238}U/^{235}U$ atom ratio of 135.7 (2.9 sigma from natural) only slightly failed to meet the 3-sigma detection criterion.

Uranium histories for several monitoring stations in Acid and Pueblo Canyons are shown in Figure 20. The graphs are based on data contained in US Geological Survey administrative reports and Laboratory annual Environmental Surveillance Reports. Records are not available for the earlier-operating period of the TA-1/TA-45 discharges; the first available water quality measurements are for 1956. Through the mid-1960s uranium concentrations in alluvial groundwater and surface water declined from about 400 μg/L (at surface water station Acid Weir in 1956) down to 5 μg/L. Concentrations less than 3 μg/L have been observed since the 1970s.

Uranium concentrations in intermediate-depth perched groundwater beneath Pueblo Canyon have been typically below 3 μg/L, with a few exceptions. There are no apparent trends in uranium concentrations in the perched groundwater. Concentrations have not exceeded 3 μg/L in Test Well 2A (sampling perched groundwater at a depth of 120 ft) or Test Well 1A (sampling at a depth of 188 ft) since the mid-1960s. A maximum uranium concentration of 10 μg/L was measured in both wells in 1961.

Table 3. Percentage of Total Uranium-235 Attributable to LANL Enriched Uranium and Depleted Uranium in Water Samples.

Station Name	Groundwater Zone	Sample Date	Fld. Prep.[a]	Log No.	Max % Enriched ^{235}U	Max % Depleted ^{235}U
Groundwater						
Ancho Spring	Regional	05-Apr-94	UF	11775-B		2.5%
Ancho Spring	Regional	05-Apr-94	UF	11775-A		2.4%
Ancho Spring	Regional	01-Jun-94	UF	11827		2.2%
PCO-2	Alluvium	22-Jun-94	UF	11930		1.3%
PCO-1	Alluvium	22-Jun-94	UF	11914		0.9%
Spring 4A	Regional	05-Apr-94	UF	11778		0.5%
Sandia Spring	Regional	04-Apr-94	UF	11779		0.5%
Spring 9	Regional	30-Sep-94	UF	12366		0.4%
Old Community Well	Regional	27-Jul-94	UF	12408A		0.4%
Spring 1	Regional	04-Apr-94	UF	11789		0.4%
Spring 2	Regional	04-Apr-94	UF	11774		0.4%
Old Community Well	Regional	27-Jul-94	UF	12408B		0.4%
Eastside Artesian Well	Regional	27-Jul-94	UF	12395		0.3%
Spring 9A	Regional	04-Apr-94	UF	11771		0.3%
PM-2	Regional	24-May-94	UF	11844		0.3%
O-4	Regional	01-Nov-94	UF	12331-B		0.3%
Westside Artesian Well	Regional	01-Jan-94	UF	12334		0.3%
Test Well 2A	Perched	31-May-94	UF	11860		0.2%
Martinez House Well	Regional	27-Jul-94	UF	12397		0.2%
Spring 3	Regional	04-Apr-94	UF	11772		0.2%
Test Well 3	Regional	02-Jun-94	UF	11895		0.2%
Halladay House Well	Regional	29-Jul-94	UF	12409A		0.2%
Spring 4	Regional	27-Sep-94	UF	12364		0.2%
Pajarito Well (Pump 2)	Regional	27-Jul-94	UF	12336		0.2%
Don Juan Playhouse Well	Regional	27-Jul-94	UF	12394		0.2%
Spring 1	Regional	27-Sep-94	UF	12379		0.2%
Test Well 3	Regional	01-Nov-94	UF	12330A		0.2%
Well G-4	Regional	25-May-94	UF	11859		0.2%
Test Well DT-9	Regional	27-Sep-94	UF	12462		0.2%
Spring 8A	Regional	05-Apr-94	UF	11773		0.2%
Halladay House Well	Regional	29-Jul-94	UF	12409C		0.2%
Doe Spring	Regional	06-Apr-94	UF	11790		0.2%
LA-5	Regional	29-Jul-94	UF	12407		0.2%
Spring 5B	Regional	28-Sep-94	UF	12376		0.2%
Halladay House Well	Regional	29-Jul-94	UF	12409B		0.2%
Test Well 3	Regional	01-Nov-94	UF	12330B		0.2%
Spring 2	Regional	27-Sep-94	UF	12380		0.2%
Spring 8A	Regional	28-Sep-94	UF	12362		0.2%
Spring 5	Regional	28-Sep-94	UF	12360		0.1%
Test Well DT-10	Regional	27-Sep-94	UF	12463		0.1%
Sanchez House Well	Regional	27-Jul-94	UF	12337		0.1%
Spring 3A	Regional	27-Sep-94	UF	12382		0.1%

Table 3. Percentage of Total Uranium-235 Attributable to LANL Enriched Uranium and Depleted Uranium in Water Samples (Cont.)

Station Name	Aquifer	Sample Date	Fld. Prep.[a]	Log No.	Max % Enriched ^{235}U	Max % Depleted ^{235}U
Groundwater (Cont.)						
Spring 3	Regional	27-Sep-94	UF	12381		0.1%
Spring 4A	Regional	27-Sep-94	UF	12359		0.1%
Spring 8B	Regional	28-Sep-94	UF	12365		0.1%
PM-4	Regional	24-May-94	UF	11838		0.1%
Doe Spring	Regional	30-Sep-94	UF	12368		0.1%
MCO-7.5	Alluvium	27-Jun-94	UF	11918		0.1%
Otowi House Well	Regional	29-Jul-94	UF	12398		0.1%
Spring 3AA	Regional	27-Sep-94	UF	12383		0.1%
Spring 3A	Regional	04-Apr-94	UF	11777		0.1%
Sandia Spring	Regional	26-Sep-98	F	15237		0.1%
PM-2	Regional	17-Nov-98	UF	15257		0.05%
Water Canyon Gallery	Bandelier Tuff	01-Nov-94	UF	12332C		0.04%
Spring 10	Regional	30-Sep-94	UF	12370		0.04%
Water Canyon Gallery	Bandelier Tuff	01-Nov-94	UF	12332B		0.03%
Water Canyon Gallery	Bandelier Tuff	01-Nov-94	UF	12332A		0.03%
Pajarito Well (Pump 2)	Regional	17-Nov-98	UF	15239		0.03%
Pajarito Well (Pump 2)	Regional	17-Nov-98	UF	15256		0.02%
New Community Well	Regional	17-Nov-98	UF	15254		0.01%
O-4	Regional	01-Nov-94	UF	12331-A	0.002%	
Old Community Well	Regional	17-Nov-98	UF	15243	0.01%	
Spring 6	Regional	28-Sep-94	UF	12373	0.01%	
Sandia Spring	Regional	27-Sep-94	UF	12363	0.02%	
Test Well 4	Regional	20-Jun-94	UF	11896	0.02%	
Test Well 1A	Perched	31-May-94	UF	11861	0.03%	
Spring 1	Regional	28-Sep-98	F	15236	0.1%	
Pajarito Well (Pump 2)	Regional	17-Nov-98	UF	15255	0.1%	
Spring 9	Regional	30-Sep-98	F	15238	0.1%	
Test Well 1	Regional	31-May-94	UF	11862	0.1%	
Sacred Spring	Regional	28-Jul-94	UF	12335	0.1%	
Spring 3	Regional	09-Nov-94	UF	12493	0.1%	
PM-5	Regional	24-May-94	UF	11840	0.2%	
O-4	Regional	16-Nov-98	UF	15247	0.2%	
Eastside Artesian Well	Regional	17-Nov-98	UF	15252	0.2%	
Spring 9A	Regional	30-Sep-94	UF	12369	0.2%	
Spring 5A	Regional	28-Sep-94	UF	12374	0.4%	
O-4	Regional	16-Nov-98	UF	16319	0.4%	
Basalt Spring	Perched	28-Jul-94	UF	12410A	0.4%	
Well G-1A	Regional	24-May-94	UF	11842	0.4%	
Spring 4A	Regional	09-Nov-94	UF	12494	0.4%	
New Community Well	Regional	17-Nov-98	UF	16320	0.5%	
MCO-7	Alluvium	27-Jun-94	UF	11931	0.8%	
O-4	Regional	16-Nov-98	UF	15246	0.8%	
Pajarito Well (Pump 2)	Regional	17-Nov-98	UF	16323	0.8%	

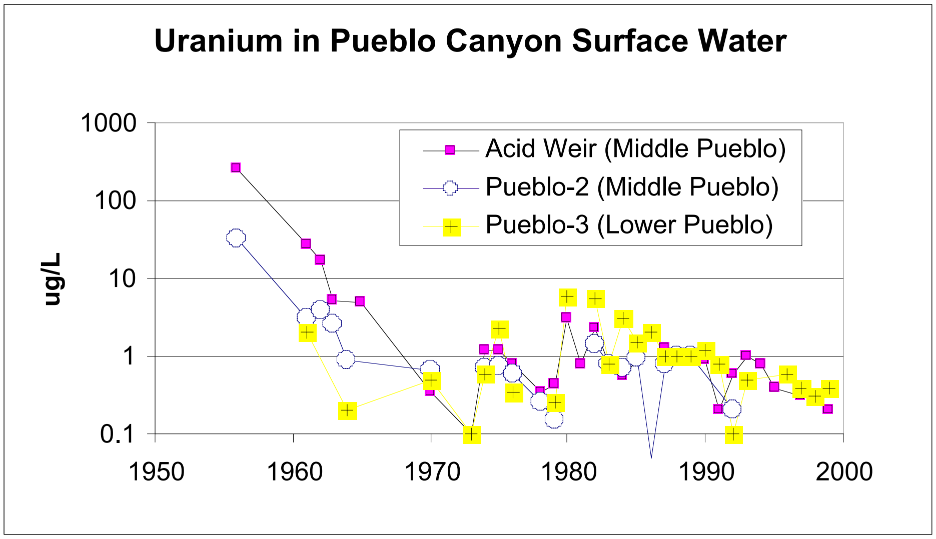
Table 3. Percentage of Total Uranium-235 Attributable to LANL Enriched Uranium and Depleted Uranium in Water Samples (Cont.)

Station Name	Aquifer	Sample Date	Fld. Prep.[a]	Log No.	Max % Enriched ^{235}U	Max % Depleted ^{235}U
Groundwater (Cont.)						
Spring 4A	Regional	29-Sep-98	F	15242	0.9%	
PM-2	Regional	17-Nov-98	UF	16324	1.0%	
LAO-0.7	Alluvium	01-Jan-94	UF	11929	1.0%	
O-4	Regional	16-Nov-98	UF	15258	1.0%	
Old Community Well	Regional	17-Nov-98	UF	16321	1.1%	
Test Well 8	Regional	20-Dec-99	UF	16356	1.2%	
Spring 2	Regional	28-Sep-98	F	15240	1.3%	
Well G-2	Regional	16-Nov-98	UF	16325	1.4%	
Test Well 2	Regional	31-May-94	UF	11863	1.6%	
LAO-1	Alluvium	09-Jun-94	UF	11891	1.6%	
Well G-2	Regional	24-May-94	UF	11841	1.6%	
Water Canyon Gallery	Bandelier Tuff	24-May-94	UF	11839	1.8%	
LAO-4	Alluvium	06-Jun-94	UF	11894	3.6%	
LAO-4.5	Alluvium	06-Jun-94	UF	11912	4.4%	
LAOR-1	Alluvium	01-Jan-94	UF	11928	8.4%	
APCO-1	Alluvium	20-Jun-94	UF	11913	9.2%	
LAO-3	Alluvium	07-Jun-94	UF	11893	9.4%	
MCO-6	Alluvium	27-Jun-94	UF	11917	15.0%	
MCO-5	Alluvium	23-Jun-94	UF	11916	18.3%	
O-4	Regional	24-May-94	UF	11843	18.4%	
MCO-4	Alluvium	23-Jun-94	UF	11915	39.0%	
LAO-2	Alluvium	09-Jun-94	UF	11892	44.5%	
Surface Water						
Cochiti Middle		06-Apr-94	UF	11787		1.0%
Frijoles at Rio Grande		06-Apr-94	UF	11780		0.9%
Rio Grande below LA Canyon		04-Apr-94	UF	11788		0.3%
Frijoles at Rio Grande		30-Sep-94	UF	12371		0.3%
Los Alamos Canyon Reservoir		14-Jul-94	UF	11932		0.2%
Pajarito Canyon		20-May-94	UF	12378		0.1%
Frijoles at Monument HQ		28-Jun-94	UF	11857		0.1%
Chaquehui at Rio Grande		29-Sep-94	UF	12367		0.1%
Rio Grande at Frijoles (bank)		29-Sep-94	UF	12372	0.7%	
Mortandad at GS-1		23-Jun-94	UF	11897	8.4%	

[a]Codes: UF = non-filtered; F = filtered.

Table 4. Comparison of Acid/Pueblo Canyon Waters Indicated to Possibly Contain Laboratory-Derived Uranium against EPA Drinking Water Standard (30 μg/L).

Station	Total U in TIMS Sample (μg/L)	Percentage of EPA Standard	Percentage of Total ^{235}U in Sample Attributable to LANL
APCO-1	0.8	3	9



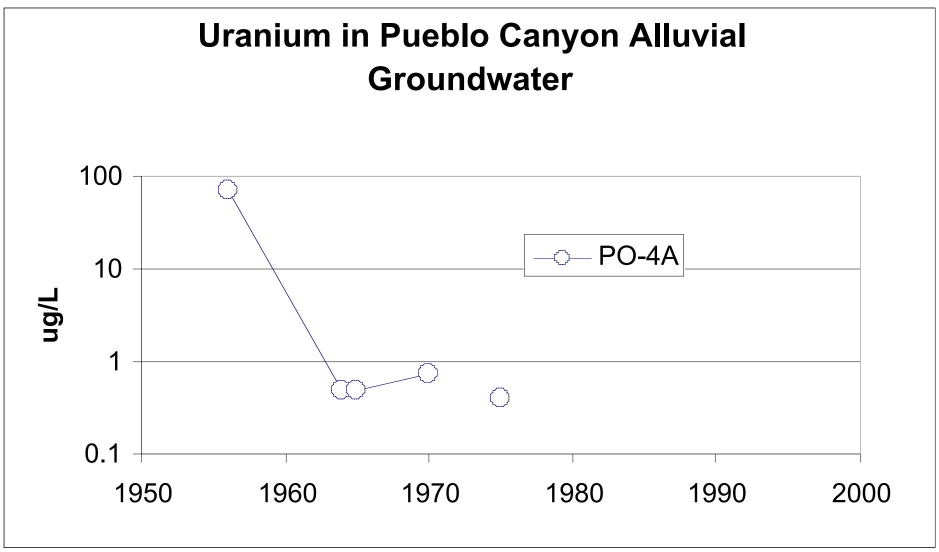
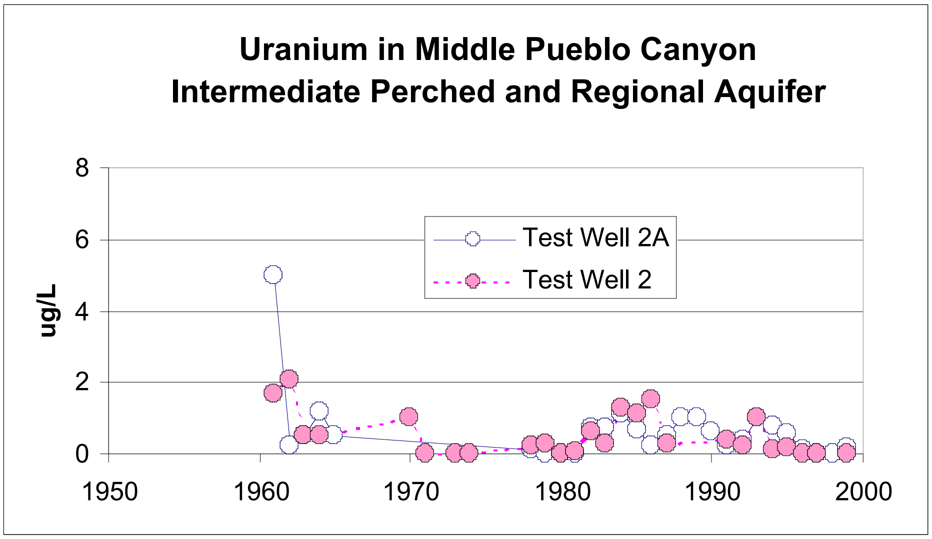


Figure 20. Uranium histories (average annual values) for surface water (Acid Weir, Pueblo-2, and Pueblo-3), alluvial groundwater (PO-4A), intermediate groundwater (Test Well 1A, Test Well 2A), and regional aquifer (Test Well 1, Test Well 2) in Pueblo Canyon. Note concentrations shown in surface water and alluvial groundwater graphs are in logarithmic scale.



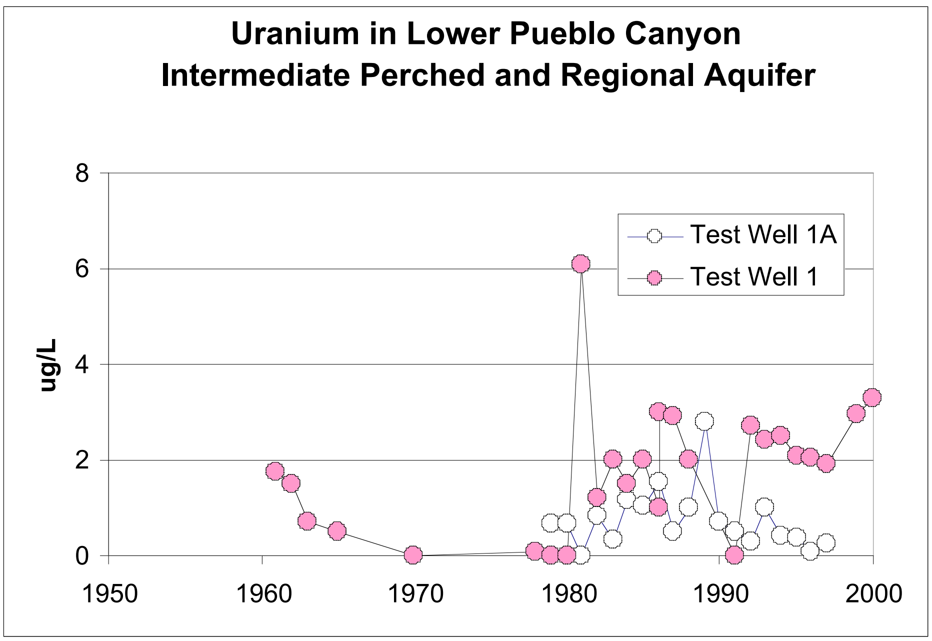


Figure 20 (Continued). Uranium histories (average annual values for surface water (Acid Weir, Pueblo-2, and Pueblo-3), alluvial groundwater (PO-4A), intermediate groundwater (Test Well 1A, Test Well 2A), and regional aquifer (Test Well 1, Test Well 2) in Pueblo Canyon.

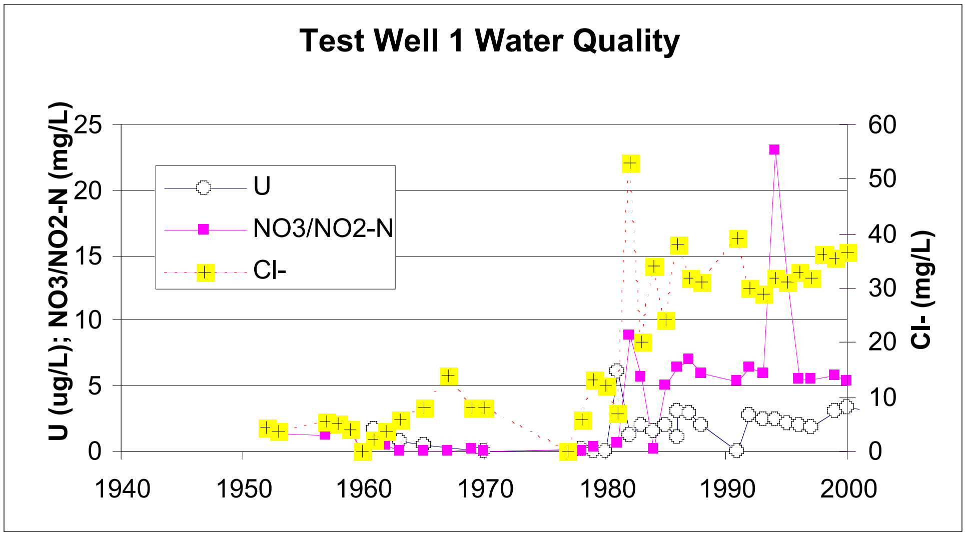


Figure 20 (Continued). Water quality trends in Test Well 1 for uranium, nitrate (as nitrogen), and chloride.

Basalt Spring lies in lower Los Alamos Canyon on San Ildefonso Pueblo land (see Figure 10). This spring discharges intermediate-depth perched groundwater and is just below the confluence of Pueblo and Los Alamos Canyons. Uranium values for Basalt Spring are slightly higher than levels in Test Well 1A in lower Pueblo Canyon (averaging 2 μg/L vs 0.8 μg/L in Test Well 1A since 1970). A hydrologic connection between Test Well 1A and Basalt Spring was established through early studies by the US Geological Survey at Los Alamos (Purtymun 1995, Weir et al. 1963). The highest total uranium concentration in Basalt Spring was 14 μg/L in a 1984 sample.

Most of the uranium measurements for the Pueblo Canyon regional aquifer wells since 1961 have been less than 3 μg/L. There are no apparent trends in the data set. Concentrations for Test Well 2 averaged less than 1 μg/L for the period of record, and in Test Well 1 less than 2 μg/L. The highest value in these wells was 6 μg/L in Test Well 1 in 1981.

In lower Pueblo Canyon, an upward trend in regional aquifer uranium concentrations began about 1980 in Test Well 1. The uranium concentrations rise is also accompanied by increases in nitrate and chloride, as shown in Figure 20. The nitrate and chloride concentrations are consistent with those measured in surface water in lower Pueblo Canyon (station Pueblo 3; ESP 1999). The surface water is dominated by effluent flows from the Los Alamos County Bayo wastewater treatment plant, located approximately one mile above Test Well 1. Both nitrate and chloride are common major constituents in sewage effluents, and isotopic analyses of the nitrate in Test Well 1 show it to be likely of animal origin (Longmire 2002b). Increased discharges into lower Pueblo Canyon from the sewage plant occurred approximately in the same time period as the uranium upward trend begins. The increase in flows was primarily due to relocation of the effluent discharge point from Bayo Canyon to Pueblo Canyon. These coincidental factors suggest that increases in uranium (of natural composition) in the regional aquifer likely are associated with percolation of the effluent. It is uncertain if the surface water carries slightly elevated uranium concentrations, or if the surface water serves as an agent to leach or mobilize natural uranium from the channel sediments or underlying rocks.

In summary, during the very early days of the Laboratory radioactive effluents were discharged for about 21 years into Acid/Pueblo Canyon. The data available are incomplete to accurately describe the historical uranium releases, but concentrations more than 13 times the proposed EPA drinking water standard have been recorded. TIMS atom ratio data developed during this study identified Laboratory-derived enriched uranium in alluvial groundwater and stream sediments of the canyon floor. However, Laboratory impacts on deeper groundwater bodies were not detected. The TIMS results are consistent with decades of historical monitoring data. The monitoring record shows generally very low uranium concentrations. An upward trend in uranium concentration is evident in the regional aquifer in lower Pueblo Canyon, but concentrations remain far below (one-tenth) the EPA standard.

DP/Los Alamos Canyon

Los Alamos Canyon received treated and untreated industrial effluents containing radionuclides for a long duration. Starting in the mid-1940s with the Manhattan Project, there were releases of treated and untreated effluents from TA-1. Several research reactors located in the canyon floor at TA-2 contributed some release of water and radionuclides (Rogers 1998). The largest historical source, however, likely was the industrial waste treatment plant at TA-21. From 1952 to 1986, the plant served the former plutonium-processing facility and assorted actinide chemistry research laboratories. Effluent from the TA-21 plant was discharged in DP Canyon, a tributary to Los Alamos Canyon.

TIMS measurements show widespread presence of anthropogenic uranium in the canyon at shallow depths. Enriched uranium was measured in alluvial groundwater samples along an approximately 10-mile reach in middle Los Alamos Canyon from immediately below the Omega West Reactor downstream to near SR 4. Table 5 summarizes the TIMS results for wells in the drainage system containing possible anthropogenic uranium. The highest degree of Laboratory impact (44% enriched ^{235}U) was seen in well LAO-2 located below the confluence with DP Canyon; enrichment declined quickly to less than 10 percent in all downgradient wells (Figure 21). Enriched uranium was also detected offsite in a sediment sample from lower Los Alamos Canyon near the Otowi Bridge (Gallaher and Efurd 2002).

Laboratory-derived uranium was not identified in regional aquifer monitoring well Test Well 3, located in Los Alamos Canyon just below the intersection with DP Canyon.

Table 5. Comparison of DP/Los Alamos Canyon Waters Indicated to Possibly Contain Laboratory-Derived Uranium against Proposed EPA Drinking Water Standard (30 μg/L). Samples collected in 1994.

Station	Total Uranium Concentration in TIMS Sample (μg/L)	Percentage of EPA Standard	Percentage of Total U in Sample Attributable to LANL
LAOR-1	6.7	22	8
LAO-1	0.14	0.5	2
LAO-2	0.09	0.3	44
LAO-3	0.18	0.6	9
LAO-4	0.11	0.4	4
LAO-4.5	0.16	0.5	4

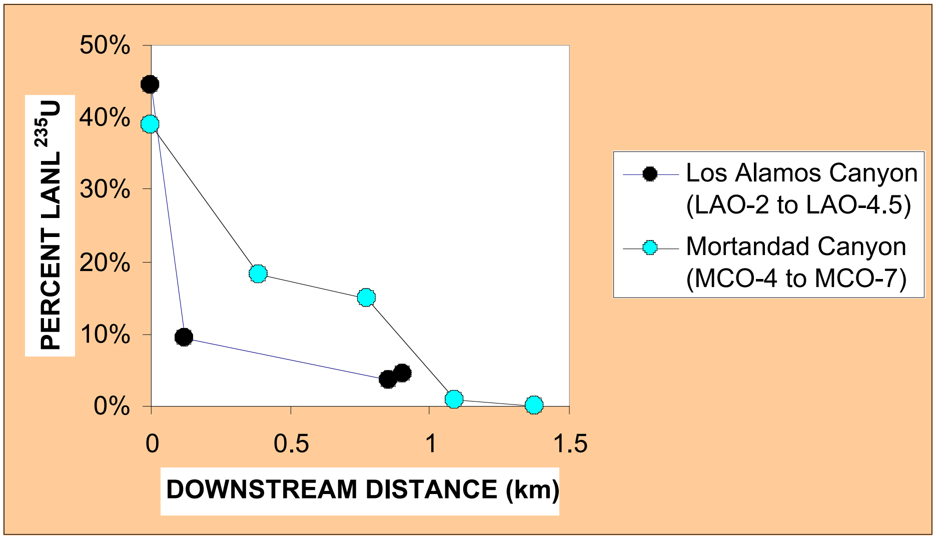


Figure 21. Downstream changes in proportion of uranium-235 derived from Los Alamos National Laboratory in alluvial groundwater, Los Alamos and Mortandad Canyons, June 1994.

The origin of the Laboratory-derived uranium in the Los Alamos Canyon groundwater is likely past discharges from TA-1 into upper Los Alamos Canyon in the 1940s and more recent discharges from TA-21 into DP Canyon. Enriched uranium is detectable in Los Alamos Canyon although the effluent discharges into DP Canyon ceased in the mid-1980s and the alluvial groundwater is seasonally flushed with natural recharge. Therefore, the probable source of the residual enriched uranium is contaminated alluvium in the canyon floor.

Uranium histories for several monitoring stations in DP/Los Alamos Canyon in the 1960s through 1990s are shown in Figure 22. The graphs are based on US Geological Survey administrative reports and annual Environmental Surveillance Reports. Routine measurements of uranium in Los Alamos Canyon waters began in the mid-1960s. Peak uranium concentrations measured in the drainage system occurred in DP Canyon over the seven-year period 1978–1984. During this period, uranium concentrations in surface water averaged about 250 μg/L and ranged up to 700 μg/L at station DPS-1. Uranium levels in DP Canyon surface waters have decreased dramatically since discharge from the TA-21 treatment facility halted in 1986 to less than 3 μg/L.

The surface water releases of uranium in DP Canyon have not had a corresponding major impact in the Los Alamos Canyon alluvial groundwater. In 30 years of monitoring, uranium concentrations in alluvial groundwater in Los Alamos Canyon wells LAO-2, LAO-3, LAO-4, LAO-4.5, and LAO-5, located below the confluence with DP Canyon, have remained below 10 μg/L, except for one value. The maximum concentration of 50 μg/L was found in well LAO-2 in 1993.

Regional aquifer monitoring well Test Well 3 is located in Los Alamos Canyon just below the confluence with DP Canyon. Between 1961 and 1997, uranium concentrations have averaged 1.4 μg/L and display no apparent trends. A maximum value of 12 μg/L was measured in 1968. Other regional aquifer wells in the drainage are water supply well O-4 in middle Los Alamos Canyon and wells located in lower Los Alamos Canyon on Pueblo of San Ildefonso land. Uranium results for these wells are discussed in later sections.

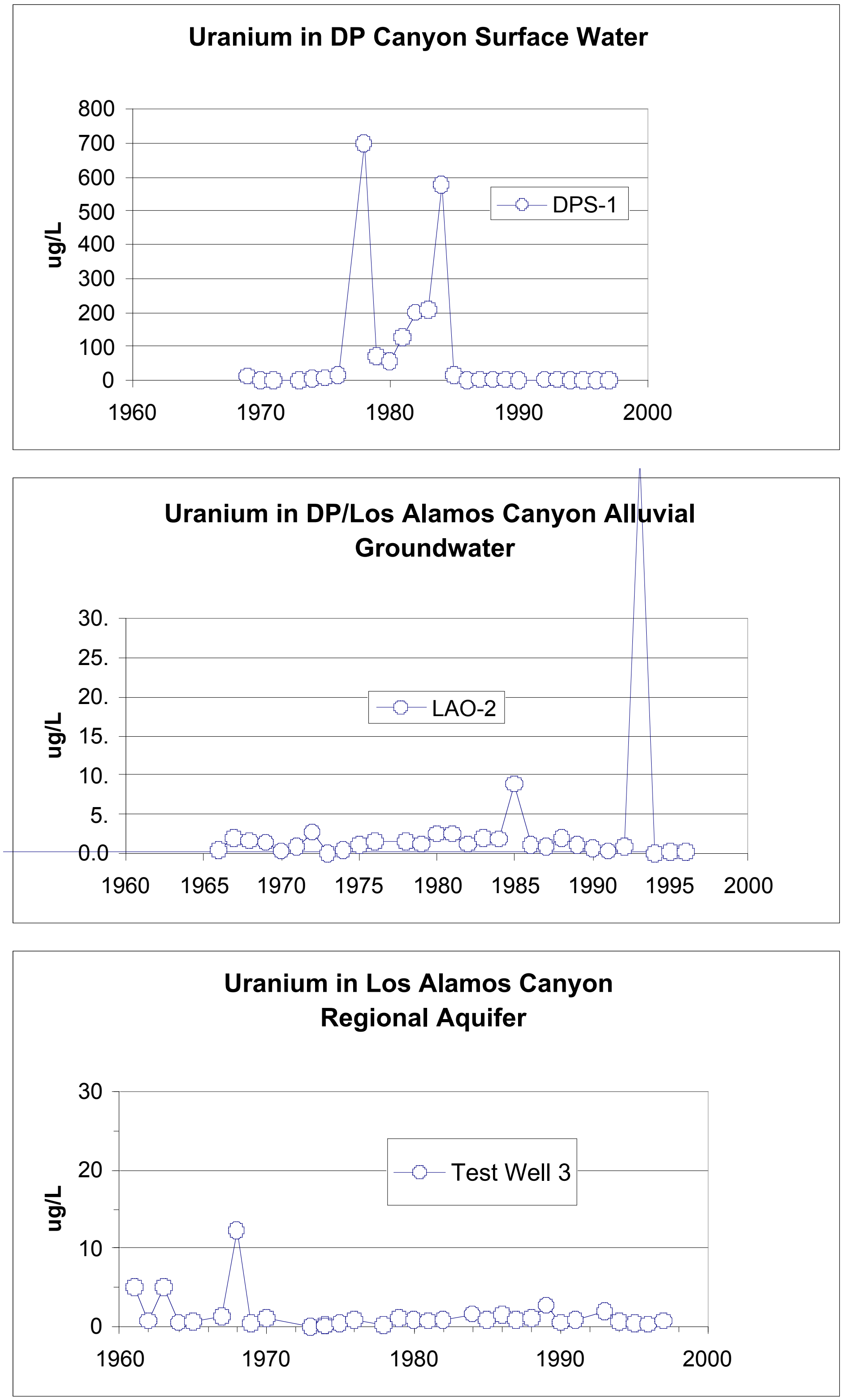


Figure 22. Uranium histories (average annual values) for surface water (DPS-1), alluvial groundwater (LAO-2), and the regional aquifer (Test Well 3) in DP/Los Alamos Canyon.

Mortandad Canyon and the TA-50 Radioactive Liquid Waste Treatment Facility

Mortandad Canyon has a small drainage area that heads in the Laboratory's main technical area at TA-3. Uranium discharges into the canyon likely started in the early 1950s from numerous potential Laboratory sources, including treatment plants at TA-3 (Sigma Building) and at TA-35 (LANL 1997, Purtymun 1964). Effluent discharges from the TA-35 treatment plant occurred from 1951 to 1963 to a branch of Mortandad Canyon, but only limited records are available regarding its discharge history. Numerous spills and accidental discharges at the plant and reactors at the site also took place. Radioactive contamination from these early discharges probably has been largely obscured by subsequent TA-50 discharges into the canyon.

The Laboratory's only current discharge of radioactive liquid effluent is from the TA-50 RLWTF into Mortandad Canyon. The TA-50 effluents infiltrate the stream channel and maintain a saturated zone in the alluvium extending about 2.2 mi downstream from the outfall. The easternmost extent of saturation is onsite, about 1 mi west of the boundary between the Laboratory and the Pueblo of San Ildefonso. Continuous flow of surface water along the drainage has not been observed to reach the Pueblo of San Ildefonso since studies began in the early 1960s (Stoker et al. 1991).

Based on the TIMS atom ratios, Laboratory-derived uranium is identifiable in Mortandad Canyon surface water below the outfall and in the most upstream alluvial groundwater wells. Table 6 summarizes the TIMS results for Mortandad Canyon. Uranium enriched in uranium-235 and containing non-natural uranium-236 was measured in shallow wells MCO-4, MCO-5, and MCO-6 located from 3 to 5 mi downstream of the TA-50 outfall. The degree of enrichment progressively declines downstream: The $^{238}U/^{235}U$ atom ratios for these wells were 84, 112, and 117, respectively, compared to the atom ratio of 137.88 found in natural uranium. These samples contain $^{236}U/^{235}U$ atom ratios that are highly skewed when compared with other waters at Los Alamos, and represent a unique signature (see Figure 13). The uranium isotopic signature at these stations is clearly anthropogenic and highly distinct from other drainages at the Laboratory. The general source of the uranium, however, is unknown and is not primarily from the discharge of modern weapons uranium (enriched).

Anthropogenic uranium was not indicated in the most downgradient alluvial wells sampled (MCO-7 and 7.5). These results, combined with the decreasing enrichment in uranium-235 downstream, indicate that uranium transport through the alluvium is retarded relative to the movement of the groundwater. Horizontal groundwater flow velocities through the alluvium are relatively high (2 to 60 ft/day), and earlier research shows considerable mixing of solutes in the saturated zone (Purtymun et al. 1983).

Table 6. Comparison of Mortandad Canyon Waters Indicated to Possibly Contain Laboratory-Derived Uranium against Proposed EPA Drinking Water Standard (30 μg/L). All data from 1994 samples.

Station	Total U in TIMS Sample (μg/L)	Percentage of EPA Standard	Percentage of Total ^{235}U in Sample Attributable to LANL
GS-1	0.38	1	8
MCO-4	1.4	5	39
MCO-5	1.9	6	18
MCO-6	2.9	10	15

The uranium in the regional aquifer at Test Well 8 was of natural isotopic composition, and Laboratory-derived uranium was not detected. Test Well 8 is located in middle Mortandad Canyon approximately 2.5 mi below the TA-50 outfall.

Uranium histories for Mortandad Canyon are shown in Figure 23. Annual average uranium concentrations in Mortandad Canyon surface water below the outfall have been below 5 μg/L since measurements began in 1962. The long-term average concentration at surface water station GS-1 is 1.3 μg/L. Alluvial groundwater at MCO-3, the well closest to the TA-50 outfall, showed the highest annual average concentration at 7.3 μg/L. This maximum value is 24 percent of the proposed EPA drinking water standard. Mean alluvial groundwater uranium concentrations for all stations over the period of record is 4.4 μg/L.

Regional aquifer uranium concentrations in Test Well 8 over the period of record are uniformly low and do not exceed 2 μg/L.

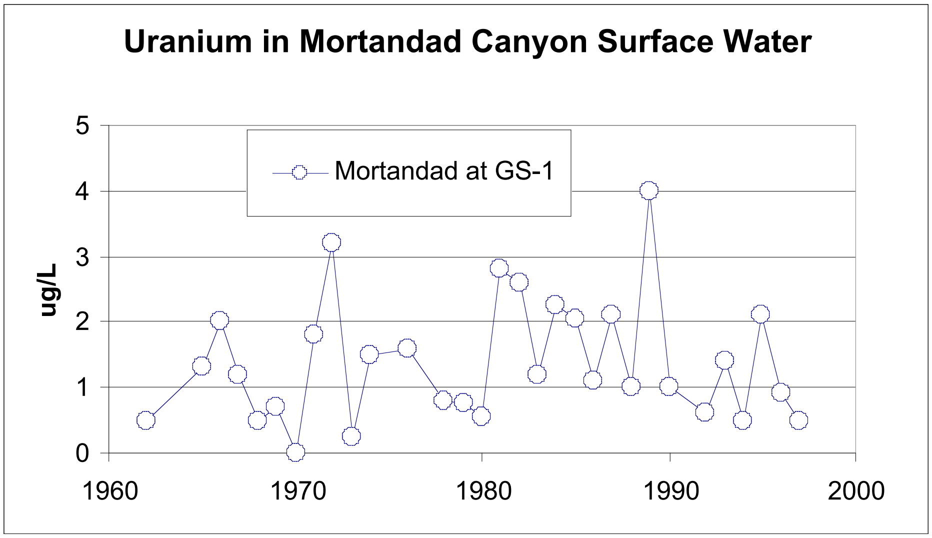
Los Alamos Water Supply Wells

Water supply for Los Alamos County is drawn from wells in three fields. Approximately two-thirds of the water produced comes from the onsite Pajarito Mesa and Otowi well fields, with the remainder from the Guaje well field, located off site in Guaje Canyon on US Forest Service lands northeast of the Laboratory (McLin et al. 1998). The Pajarito Mesa well field contains five wells located in Sandia Canyon and Pajarito Canyon and on mesa tops between these canyons. Two wells comprise the Otowi well field; one well is located in lower Pueblo Canyon and the other in middle Los Alamos Canyon at the junction with DP Canyon. The Guaje well field consists of seven wells. Since the time samples were collected for this study, all but one (G-1A) of the original Guaje wells have been replaced with new production wells; most of the older wells have been plugged and abandoned.

Some of the wells of the Pajarito Mesa and Otowi well fields are located near or downgradient from potential Laboratory sources. The Guaje well field is offsite and not located near any major sources of uranium.

The supply wells are completed in the regional aquifer to noteworthy depths. The screened intervals in the wells range in height from 400 to 500 ft in the Guaje well field and 1,200 to 1,600 ft in the Pajarito Mesa and Otowi well fields. Samples collected from these wells thus represent average mixtures for water drawn into the well screens from a large portion of the subsurface (Purtymun 1995; Rogers 1998). Uranium values from each of these well fields average less than 2 μg/L. The maximum value seen during the period of record was 5.2 μg/L.

Initial TIMS analyses indicated enriched uranium in samples from well G-2 in the Guaje well field and in well O-4 in the Otowi well field. None of the initial results were confirmed with subsequent sampling and analyses. With all results averaged, natural uranium isotopic compositions are indicated for G-2 and O-4. All other regional aquifer wells near G-2 (G-1A and G-4) or O-4 (Test Well 3) showed natural isotopic compositions. The initial results are further suspect, given the noteworthy distance from G-2 to any known source of enriched uranium, the great depth of O-4, and the absence of enriched uranium at other adjacent regional aquifer wells. Total uranium concentrations were less than 1 μg/L in each of the G-2 and O-4 samples analyzed by TIMS. Figure 24 displays the uranium histories for these two wells.



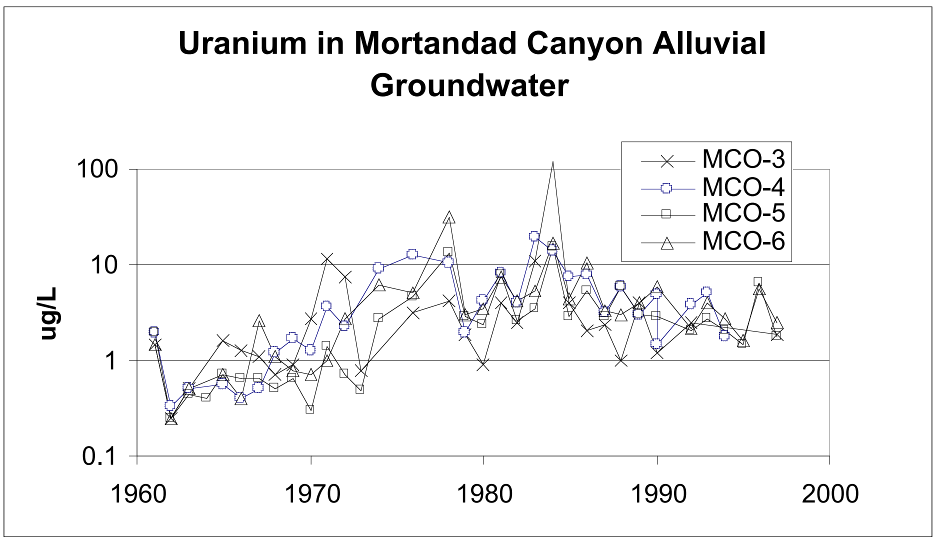


Figure 23. Uranium histories (average annual values) for Mortandad Canyon surface water (GS-1), alluvial groundwater (MCO-3, -4, -5, -6), and the regional aquifer (Test Well 8). Note that concentrations in alluvial groundwater chart are shown in logarithmic scale.

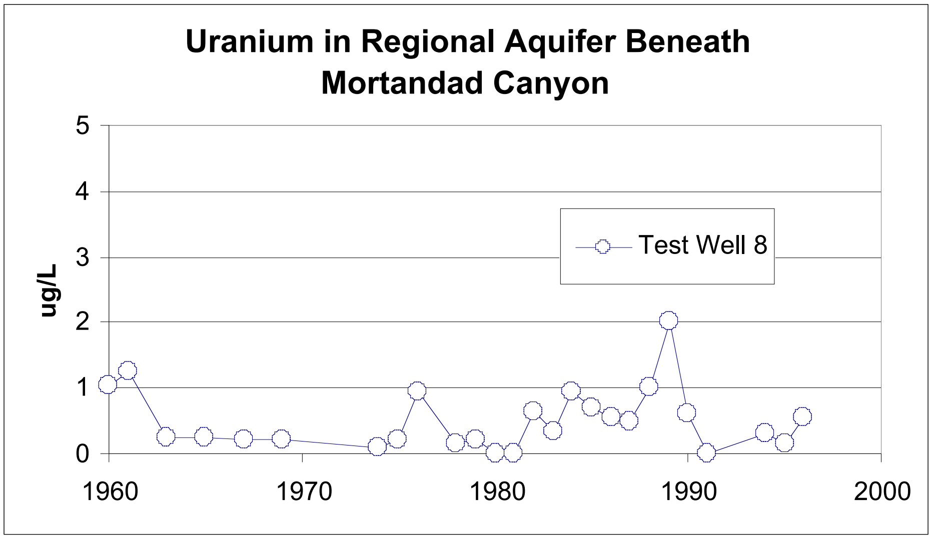


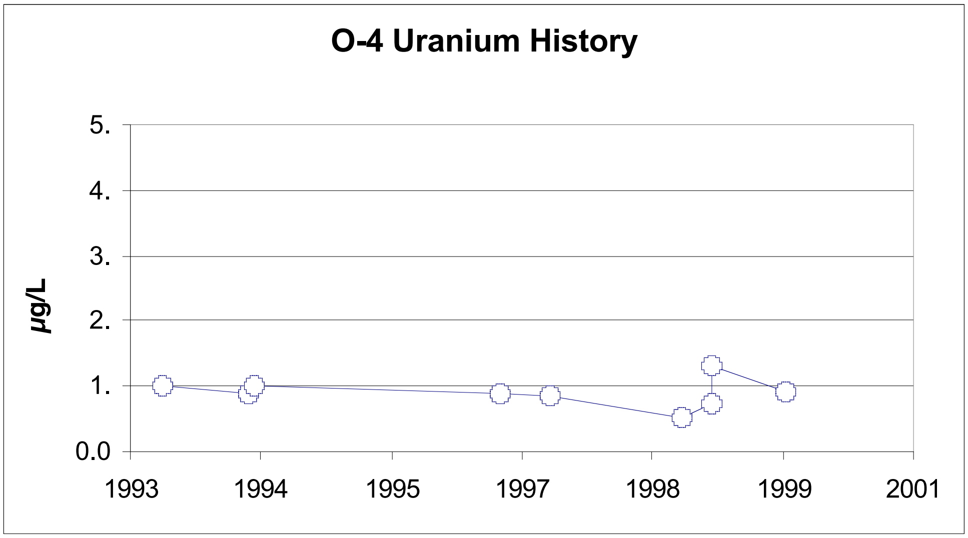
Figure 23 (Continued). Uranium histories (average annual values) for Mortandad Canyon surface water (GS-1), alluvial groundwater (MCO-3, -4, -5, -6), and the regional aquifer (Test Well 8).

San Ildefonso Pueblo Wells

San Ildefonso Pueblo residents are supplied water from a combination of private household, subdivision, and community wells. To document the potential impacts of Laboratory operations on lands belonging to the Pueblo, the DOE entered into a Memorandum of Understanding (MOU) with the Pueblo and the Bureau of Indian Affairs in 1987 to conduct environmental sampling on Pueblo land. The Pueblo and LANL's Environmental Surveillance Program jointly sample all potentially affected environmental media, usually yearly. Results of the annual MOU testing indicate the widespread presence of uranium at levels approaching or in excess of the EPA drinking water limit.

Between 1994 and 1998, we collected 17 samples from 11 San Ildefonso Pueblo wells for TIMS uranium isotopic composition analyses (see Figure 10). Six of the selected wells are located in or near lower Los Alamos Canyon where LANL impacts would be most likely to be evident. Results of the TIMS analyses indicate that all of the sampled San Ildefonso Pueblo wells contained natural uranium. None of the samples showed evidence of Laboratory-derived uranium. The maximum uranium concentration was 37 μg/L. Two wells contained uranium concentrations in excess of the EPA drinking water limit—the New Community well and the Old Community well—both located on the east side of the Rio Grande. The results are consistent with previous observations (ESP 1999).

We reviewed uranium histories for wells and springs in lower Los Alamos Canyon for trends. The uranium histories for some of the wells span over 30 years. The review included records from the original well field (the Los Alamos, or LA, field) developed for Los Alamos County municipal water supply in the late 1940s. Most of these wells were inoperable during the sampling for TIMS analyses, but their uranium record is extensive and provides good long-term perspective. The LA field wells were drilled to depths ranging from 882 to 2,256 ft (Purtymun 1995). Pumpage from the well field to Los Alamos stopped in 1992. The wells were later plugged and abandoned or transferred to San Ildefonso Pueblo.



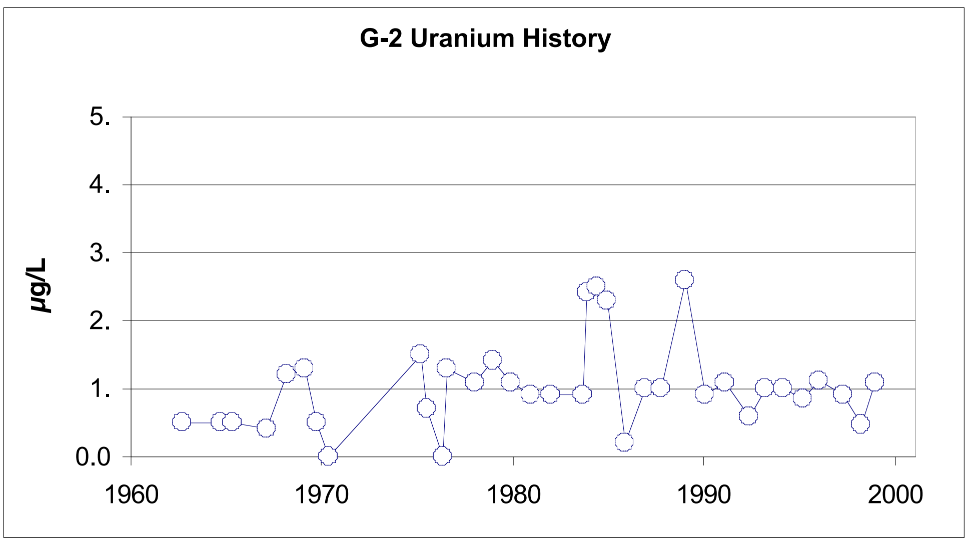


Figure 24. Uranium histories (average annual values) for regional aquifer water supply wells (G-2 and O-4).

Uranium concentrations over time for lower Los Alamos Canyon groundwater are shown in Figure 25. None of the levels in this area exceeded the EPA drinking water limit of 30 μg/L, though levels in Indian and Sacred Springs approached the limit during the late 1980s. Uranium concentrations in this area are generally much higher than found in surface waters and groundwaters on the Pajarito Plateau, as described earlier.

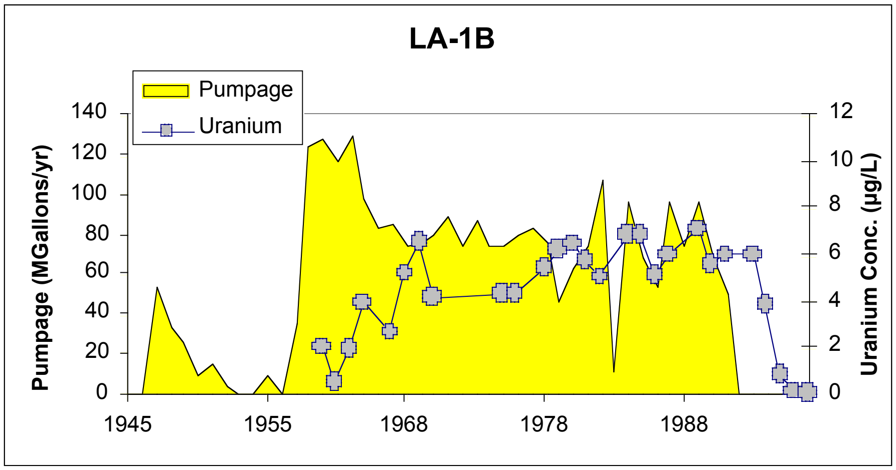
Some upward trends in uranium concentrations are evident for several wells and springs in lower Los Alamos Canyon. Our review shows that the upward trends are related to the pumping from the LA field wells. An increase in pumping triggers increases in natural uranium levels in the groundwater, as discussed further below.

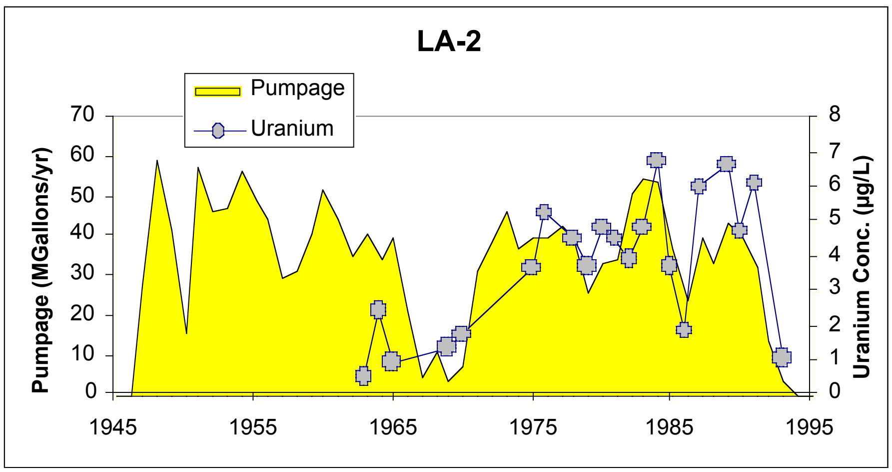
In Figure 25 we compare for individual wells the measured annual average uranium concentrations with the corresponding yearly pumpage volumes. The production volumes for each well were taken from McLin et al. (1998). Correlation is seen between concentrations and pumpage volumes at each well in the LA field. Three phases appear to control the uranium levels:

1. As groundwater pumpage from a well increases, uranium concentrations gradually rise, but with an apparent lag behind pumpage of one or two years.
2. If production volumes stabilize for several consecutive years, so do the uranium concentrations.
3. Lastly, as pumpage from the wells declines and eventually ceases in the early-1990s, uranium concentrations dramatically drop. Uranium levels stabilize at a relatively low concentration of about 2 μg/L after the well field is shut down.

Uranium histories for Spring 1 and Spring 2 also show significant rises and falls through the period of record. These are regional aquifer springs discharging along the Rio Grande at distances between 1.5 to 2 mi from the LA well field (see Figure 10).

There are several lines of evidence that suggest that the uranium is associated with very old groundwaters present near the Rio Grande. First, the higher uranium concentrations are found at wells and springs that also produce water with elevated levels of sodium, bicarbonate, boron, and chloride, among other constituents. Figure 26 shows the correspondence over time between uranium and sodium at Spring 2, for example. The largest uranium concentrations found near the Rio Grande are usually detected at Westside Artesian Well (see Figure 10), averaging about 25 μg/L since the late 1980s. The well also contains elevated average concentrations of sodium (370 mg/L), chloride (330 mg/L), bicarbonate (340 mg/L), and boron (1,700 μg/L). Elevated levels of these analytes are reflective of mineral-dissolution processes that occur when groundwater interacts long-term with earth materials in sedimentary basins (Freeze and Cherry 1976). Second, the carbon-14 age of the groundwater increases across the Pajarito Plateau from west to east (Rogers et al. 1996). Near the Rio Grande, waters older than 30,000 years have been sampled. The old waters commingle with young waters near the river, as both long and short groundwater flow paths converge at the Rio Grande, a regional groundwater discharge zone (Vesselinov and Keating 2002). In addition, stable isotopes (^{18}O and deuterium) data measured on both sides of the basin (Anderholm 1994, Blake et al. 1995) indicate the presence of very old waters near the Rio Grande that was recharged tens of thousands of years ago in a significantly colder climate (Anderholm 1994).





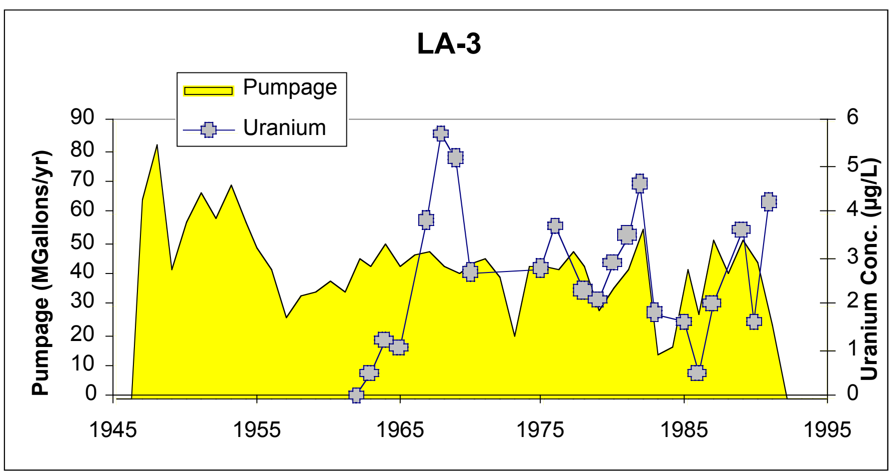
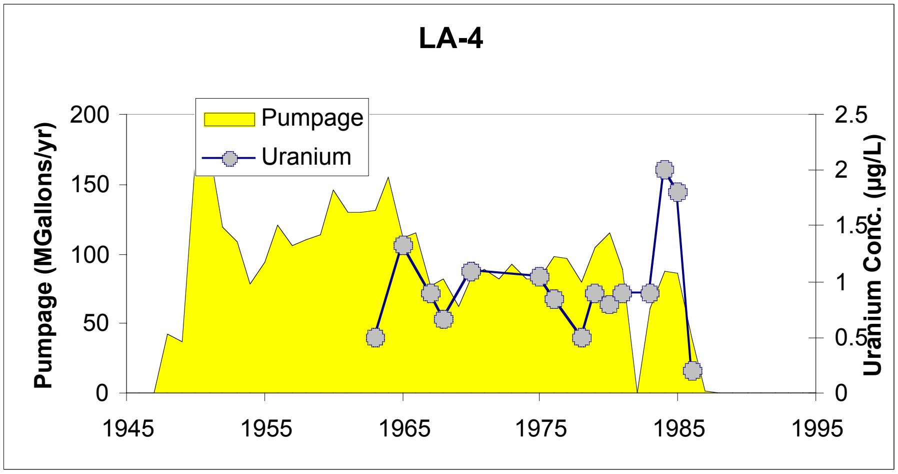
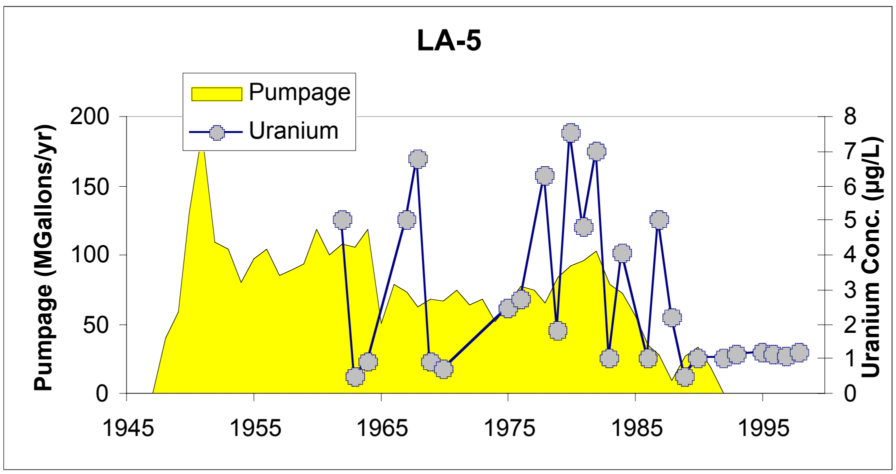


Figure 25. Annual pumpage volumes and uranium concentrations in groundwater withdrawn from individual wells located in the Los Alamos well field, 1945–1995.





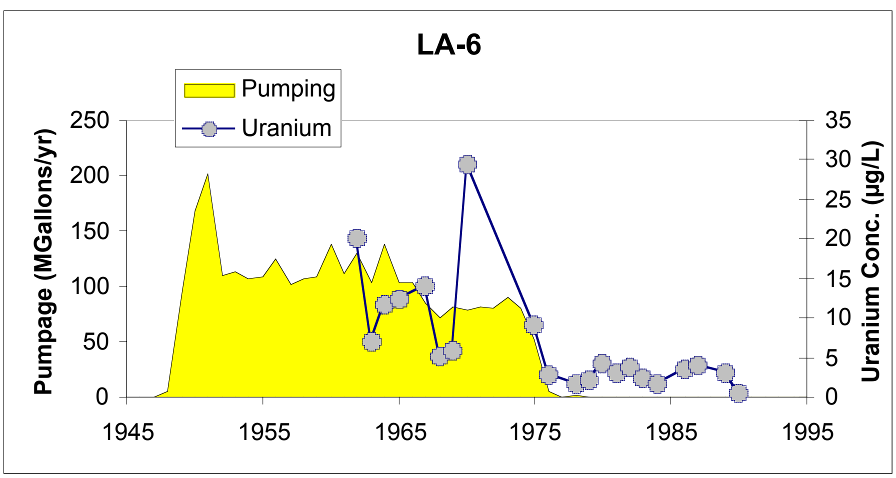


Figure 25 (Continued). Annual pumpage volumes and uranium concentrations in groundwater withdrawn from individual wells located in the Los Alamos well field, 1945–1995.

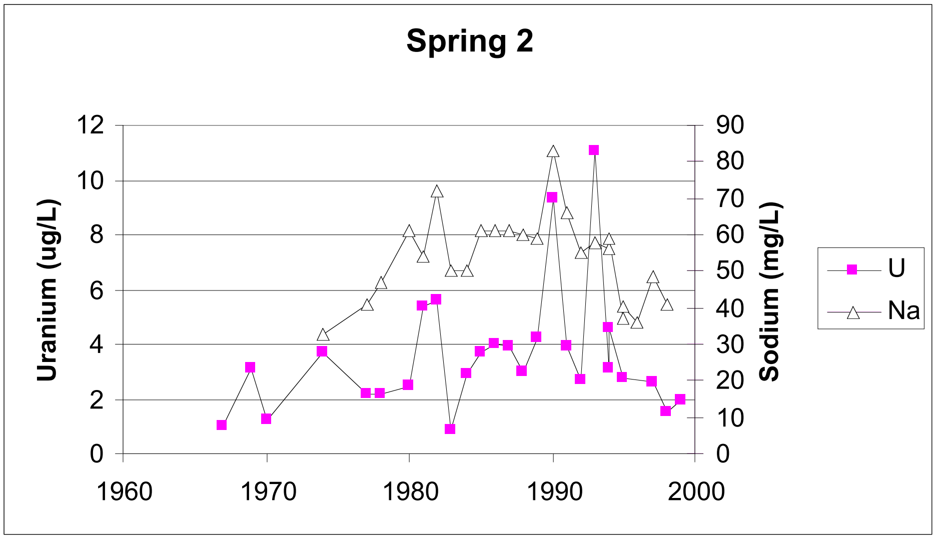


Figure 26. Correspondence since the 1970s between uranium and sodium concentrations at Spring 2.

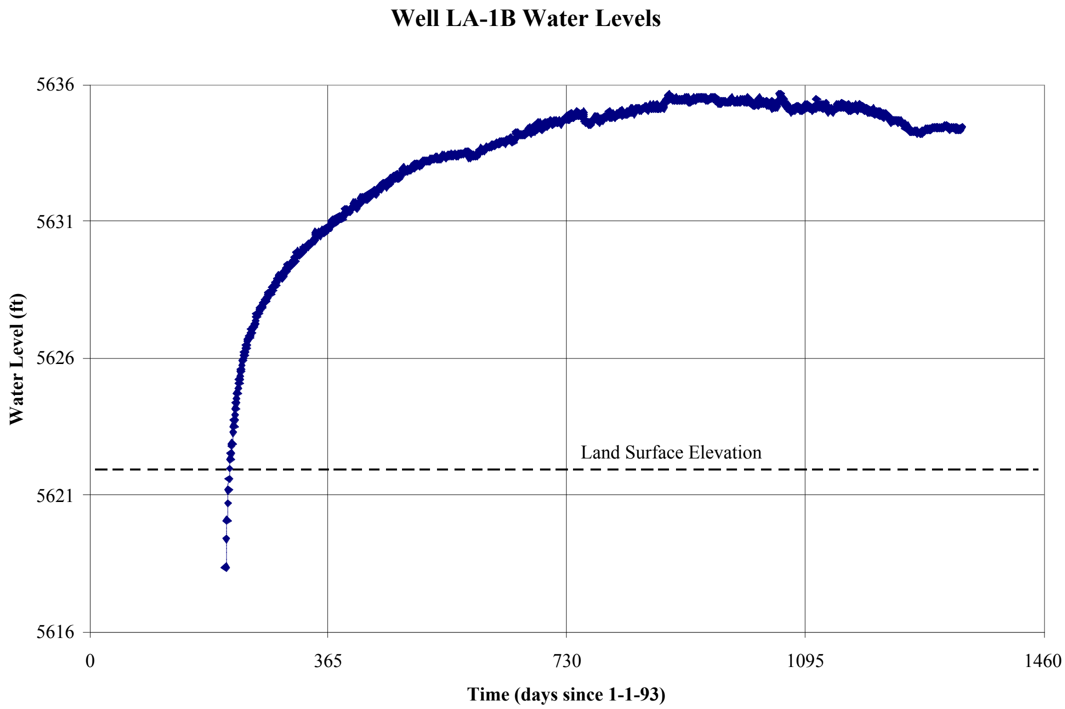
Before large-scale withdrawals started at the Los Alamos well field, there were numerous artesian wells along the river near lower Los Alamos Canyon (Theis and Conover 1962). Upward vertical gradients dominated (Vesselinov and Keating 2002), and hydraulic heads more than 20 ft above ground surface existed over a large area near the Rio Grande. Once pumping started, water levels in the production wells progressively declined 100 to 200 ft below initial conditions. Natural groundwater flow patterns thus were significantly altered and were very complex during the pumping period. After pumping ceased in the well field, water levels restored quickly to near pre-development levels, as shown for well LA-1B in Figure 27. Groundwater sampled from LA-1B during the active pumping period of age dating with trace level tritium analyses of groundwater pumped in 1991 and 1993 from well LA-1B shows water older than 60 years

We theorize that during the peak pumping periods, the proportion of older groundwater increases in the LA field wells and the natural uranium concentrations rise. Based on a limited data set collected mainly during the 1990s, there appears to be a correlation between the carbon-14 age of the groundwater adjacent to the Rio Grande and the dissolved solutes and uranium concentrations (Figure 28). Trace level tritium analyses of well LA-1B groundwater samples showed groundwater ages between 60 and 10,000 years (Blake et al. 1995) during a time period (1991–1993) when uranium concentrations in the well were near their maximum (see Figure 25). During periods of lesser pumping, relatively younger groundwaters are drawn into the wells, which contain lower uranium concentrations. The variability in uranium concentrations over time is attributable to the fluctuating pumping stresses in the well field. Upon closure of the well field, a natural balance is re-established between the older and the younger groundwaters, and the uranium levels stabilize along with the water levels in the well field.

White Rock Canyon Springs

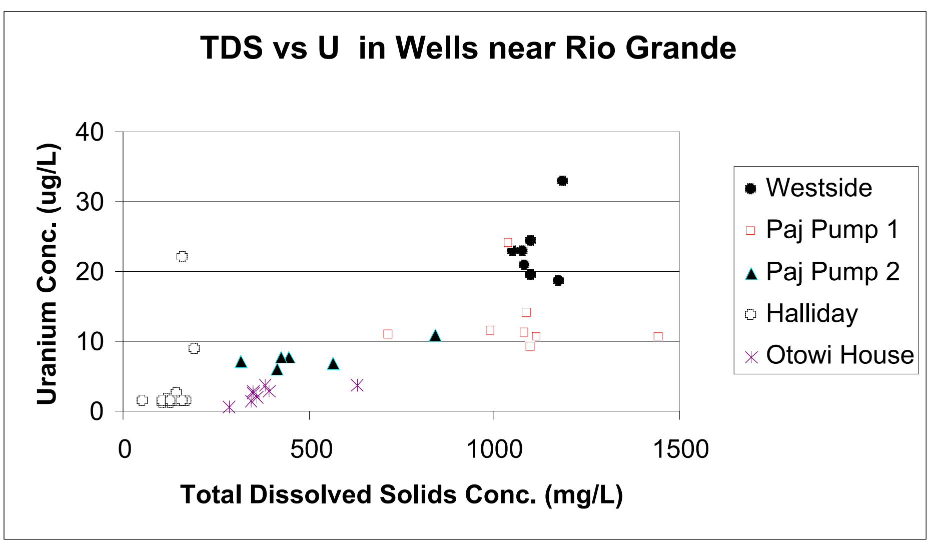
Twenty-seven springs discharge from the regional aquifer in and along the Rio Grande in White Rock Canyon (see Figure 9). The Environmental Surveillance Program has sampled annually most of the springs since about the mid-1970s.

For this study, 37 samples from 21 of the springs were submitted for TIMS analyses. Initial samples from Sandia Spring, Spring 4A, Ancho Spring, and Spring 9 suggested Laboratory influences, but only the depleted uranium finding for Ancho Spring was confirmed with subsequent sampling analyses. With all



Production from well LA-1B occurred from 1947 through 1991. This graph is modified from McLin (1996).

Figure 27. Recovery of water levels in well LA-1B, lower Los Alamos Canyon, following cessation of pumping.



The highest concentrations for both analytes are found at the Westside Artesian well. The ^{14}C age of the groundwater at the well is >35,000 years (Rogers et al. 1996).

Figure 28. Correlation between total dissolved solids (TDS) concentrations and uranium concentrations in wells near the Rio Grande and lower Los Alamos Canyon, 1988–1996.

TIMS results averaged, all the springs show natural isotopic composition, except for Ancho Spring. Table 7 summarizes the TIMS results for these stations. The maximum total uranium concentration by TIMS at these springs was 2.7 μg/L, less than 10 percent of the EPA drinking water standard.

Table 7. Comparison of White Rock Canyon Springs containing Anthropogenic Uranium against Proposed EPA Drinking Water Standard (30 μg/L)

Station	Total U in TIMS Sample (μg/L)	Percentage of EPA Standard	Percentage of Total U in Sample Attributable to LANL
Sandia Spring	1.0	3	0.5
Ancho Spring	0.65	2	2
Spring 4A	1.0	3	0.5

A complication in interpreting these results is the possibility that groundwater feeding the springs may be cross-contaminated by contact with surface soils. All of the initial samples were collected as whole, non-filtered samples and thus may contain surface soils particles that became entrained in the water sample.

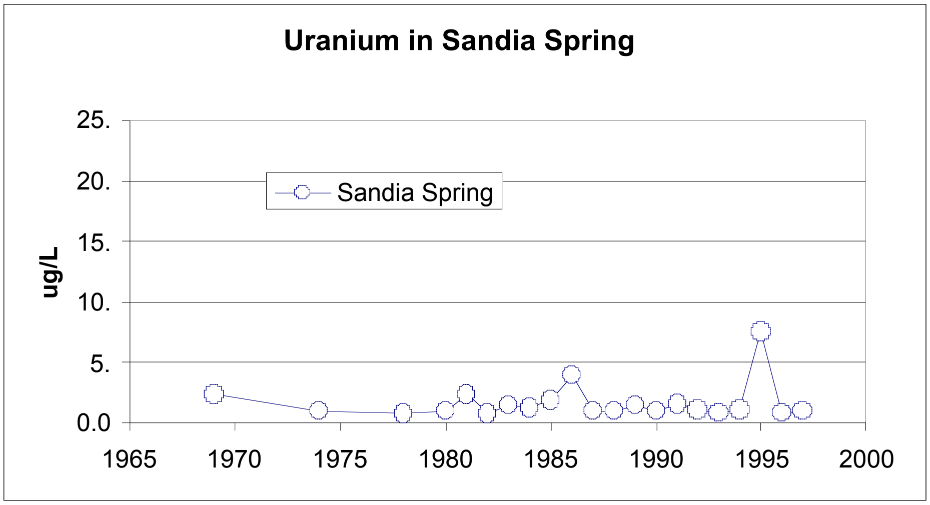
At Ancho Spring, the groundwater issues through the sandy bottom of Ancho Canyon and has the potential to pick up suspended or dissolved uranium at the discharge point. Repeat testing of Ancho Spring has confirmed the presence of depleted uranium in the water samples, but it is uncertain whether the depleted uranium is associated with the groundwater or with the stream bottom sediments. Depleted uranium has been measured in sediments within the Ancho Canyon drainage at SR 4 (Gallaher and Efurd 2002). Because of the topographic situation at the springhead it was not possible to collect a sample of the groundwater before it contacts the stream sediments. We recommend collecting several additional filtered samples from Ancho Spring (and possibly from nearby wells and springs) to compare with the non-filtered TIMS results. If depleted uranium is absent in the filtered samples, we can conclude that the groundwater has not been impacted.

The depleted uranium in the Ancho Canyon sediments is probably from water transport from firing sites. At other sites, there is evidence that suggests spring samples may be impacted by a separate airborne source of depleted uranium. Gallaher and Efurd (2002) have measured depleted uranium at two locations where water transport does not appear to be a viable transport mechanism:

- Surface soil sample collected upslope of Spring 4A in White Rock Canyon—The site is located on the canyon wall and several kilometers from any Laboratory sources.
- Sediment station A7 in Mortandad Canyon—The presence of depleted uranium (two separate samples) at the station is anomalous; all anthropogenic uranium identified upstream is highly enriched and the presence of depleted uranium at station A7 is best explained as resulting from airborne deposition from Laboratory firing sites.

Over 100,000 kg of natural and depleted uranium have been expended at Laboratory firing sites since the 1940s (Becker 1992). Many additional soil or vegetation samples would have to be collected to map out the extent of trace-level airborne deposition from the firing sites.

Uranium histories for the four springs possibly containing non-natural uranium are shown in Figure 29. Total uranium concentrations at each of the sites typically have been less than 2 µg/L over the past 30 years.



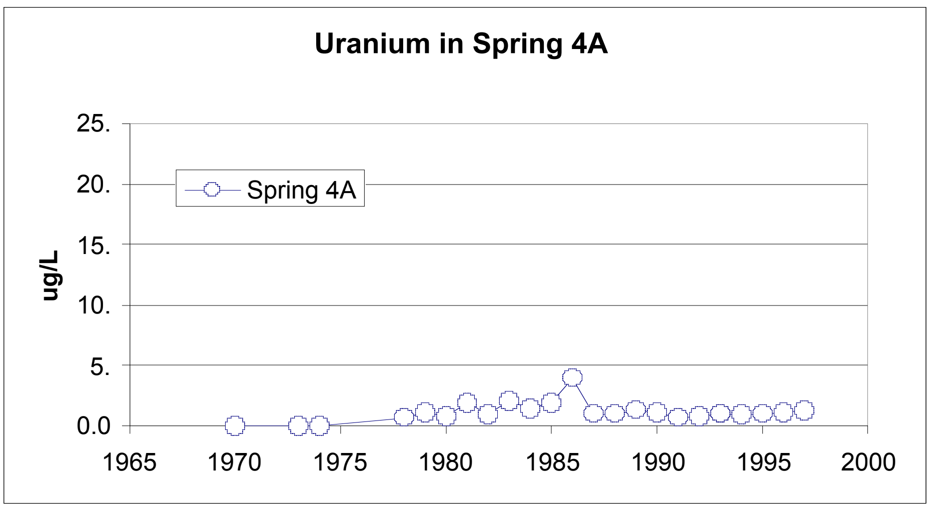
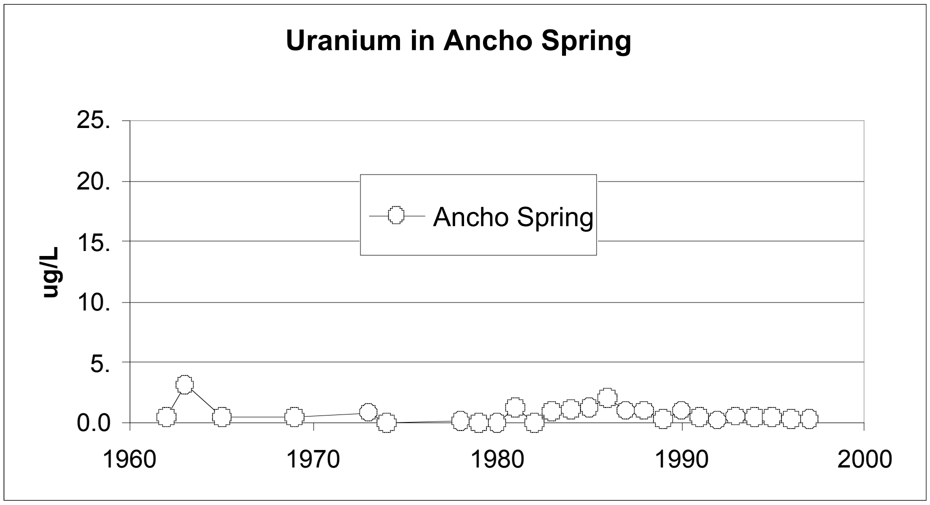


Figure 29. Uranium histories for selected White Rock Canyon springs (Sandia Spring, Spring 4A, Ancho Spring, and Spring 9).



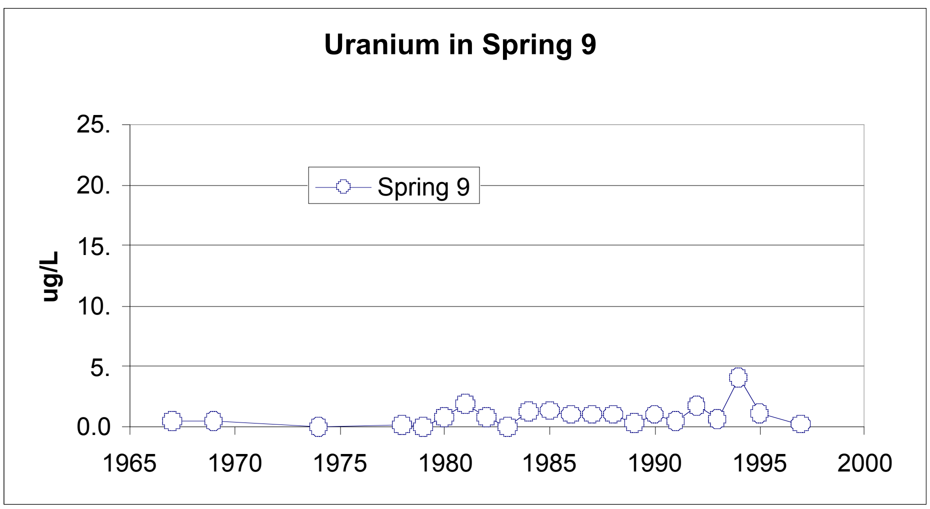


Figure 29 (Continued). Uranium histories for selected White Rock Canyon springs (Sandia Spring, Spring 4A, Ancho Spring, and Spring 9).

CONCLUSIONS

The concentrations of uranium in waters near Los Alamos are commonly low and well below regulatory limits. Based on a review of monitoring data collected in the 1990s, there is no indication of major impacts from Laboratory discharges on deep groundwater.

The preponderance (91%) of the water samples collected for this survey showed natural uranium composition. Groundwater samples showing Laboratory-derived uranium were limited to the Pajarito Plateau. Detections of isotopically modified uranium were confirmed only in shallow groundwater found in canyon bottoms, and in Ancho Spring, a White Rock Canyon deep groundwater spring. While depleted uranium was confirmed to be present in samples from Ancho Spring, it is uncertain whether the depleted uranium is associated with the groundwater or with depleted uranium-ladened stream channel sediments through which the spring issues. Additional fieldwork is recommended to determine if the groundwater at Ancho Spring has been impacted.

Of those samples indicated to contain a component of anthropogenic uranium, most were enriched in uranium-235. Enriched uranium in Los Alamos, Pueblo, and Mortandad Canyons appears to be from effluent discharges. The surface water and alluvial groundwater of Mortandad Canyon also contained the anthropogenic isotope uranium-236, providing a unique signature. Enriched uranium was also detected in some initial samples taken from intermediate-depth perched groundwater and from the regional aquifer. However, we were unable to verify any of these indications either through repeat testing of these wells and springs or through historical sampling results. When follow up TIMS results are averaged with the initial results for each of these stations, natural isotopic compositions are indicated.

Trace levels of depleted uranium were indicated in surface water samples collected in Cochiti Reservoir downstream of LANL and in Frijoles Creek, adjacent to LANL; other results from these vicinities, however, did not detect LANL uranium. The proportion of uranium-235 attributable to LANL in these surface water samples is 1 percent or less. In most cases, uranium-235 that can be attributed to the Laboratory comprises less than 2 percent of the total uranium in waters. The maximum LANL proportion identified was about 40 percent, in shallow groundwaters below effluent discharges. The greatest uranium concentration in Laboratory-impacted waters was 13 μg/L, compared to the EPA standard for drinking water systems of 30 μg/L.

Only two of the 93 water samples (3%) collected for this survey contained total uranium concentrations greater than the EPA standard for drinking water. The two samples greater than the standard were from wells located in the Rio Grande valley and are due to natural uranium found in sediments of the valley.

ACKNOWLEDGMENTS

This work was performed for the Laboratory's Environmental Surveillance Program. It builds upon decades of environmental monitoring and research conducted by Bill Purtymun and Alan Stoker. Steven Rae of the Water Quality and Hydrology Group provided continual support for this study over many years. Max Maes and Jake Martinez performed sample collection. We thank Bandelier National Monument, Los Alamos County, Pueblo de Cochiti, San Ildefonso Pueblo, and the US Forest Service for providing us access for sampling lands adjacent to LANL. Significant analytical and interpretive support was received from Don Rokop, Tim Benjamin, Clarence Duffy, Fred Roensch, Harold Poths, John Chamberlain, and Phil Hemberger. The report benefited greatly from the technical reviews of John Musgrave, Patrick Longmire, Elizabeth Keating, and David Rogers.

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APPENDIX

Table A-1 (a). Uranium Isotopic Composition of Groundwaters (TIMS Analyses)

Station Name	Sample Date	Sample Type[a]	Fld. Prep.	Log No.	Total Uranium Conc. (µg/L)	Atom Ratio $^{234}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{236}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{238}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural
Regional Aquifer Wells														
Test Wells:														
Test Well 1	31-May-94	1	UF	11862	2.56	0.0148	1.1%	45.3	-6.4E-06	675.7%	-0.1	137.75	0.35%	-0.3
Test Well 2	31-May-94	1	UF	11863	0.08	0.0180	6.7%	8.5	5.8E-04	62.4%	1.6	135.72	0.55%	-2.9
Test Well 3	02-Jun-94	1	UF	11895	0.57	0.0176	1.7%	34.1	-7.2E-05	94.9%	-1.1	138.63	0.35%	1.5
Test Well 3	01-Nov-94	1	UF	12330A	0.58	0.0177	1.2%	46.8	-3.1E-05	274.1%	-0.4	138.54	0.35%	1.3
Test Well 3	01-Nov-94	LDUP	UF	12330B	0.57	0.0181	1.3%	45.5	1.2E-04	71.2%	1.4	138.45	0.35%	1.2
Test Well 4	20-Jun-94	1	UF	11896	0.52	0.0204	1.8%	35.2	1.7E-04	74.6%	1.3	137.86	0.35%	0.0
Test Well 8	20-Dec-99	1	UF	16356	0.55	0.0177	1.7%	34.3	-8.0E-05	50.3%	-2.0	136.27	0.74%	1.3
Test Well DT-9	27-Sep-94	1	UF	12462	0.33	0.0141	2.0%	23.4	3.5E-05	511.1%	0.2	138.50	0.35%	1.3
Test Well DT-10	27-Sep-94	1	UF	12463	0.31	0.0168	2.2%	24.7	-6.0E-05	213.4%	-0.5	138.38	0.35%	1.0
Los Alamos Water Supply Wells:														
O-4	24-May-94	1	UF	11843	0.79	0.0150	4.1%	12.0	3.7E-04	74.5%	1.3	112.55	1.32%	-17.1
O-4	01-Nov-94	1	UF	12331-A	0.79	0.0163	1.2%	45.6	1.1E-04	52.3%	1.9	137.88	0.35%	0.0
O-4	01-Nov-94	LDUP	UF	12331-B	0.79	0.0166	1.2%	46.1	-1.9E-05	273.0%	-0.4	138.88	0.35%	2.0
O-4	16-Nov-98	1	UF	15258	0.66	0.0188	1.2%	51.3	6.3E-05	103.1%	1.0	136.54	0.74%	1.4
O-4	16-Nov-98	LDUP	UF	16319	0.67	0.0191	2.4%	25.5	2.4E-04	133.4%	0.7	137.39	0.79%	0.5
O-4	16-Nov-98	FDUP	UF	15246	0.95	0.0167	2.9%	18.8	-1.8E-06	15320.6%	0.0	136.75	0.78%	1.1
O-4	16-Nov-98	FTRP	UF	15247	0.53	0.0213	1.2%	52.3	9.2E-05	99.1%	1.0	137.62	0.74%	0.3
PM-2	24-May-94	1	UF	11844	0.31	0.0144	4.7%	10.0	3.8E-05	435.9%	0.2	138.97	0.39%	2.0
PM-2	17-Nov-98	1	UF	15257	0.01	0.0141	4.7%	9.7	-5.6E-05	899.5%	-0.1	138.04	0.75%	0.1
PM-2	17-Nov-98	LDUP	UF	16324	0.01	0.0139	12.0%	3.8	6.6E-04	224.2%	0.4	136.56	0.80%	1.3
PM-4	24-May-94	1	UF	11838	0.37	0.0149	1.8%	27.2	4.8E-05	218.0%	0.5	138.23	0.35%	0.7
PM-5	24-May-94	1	UF	11840	0.53	0.0137	3.0%	14.5	2.8E-04	60.3%	1.7	137.65	0.38%	-0.4

Table A-1 (a). Uranium Isotopic Composition of Groundwaters (TIMS Analyses) (Cont.)

Station Name	Sample Date	Sample Type[a]	Fld. Prep.	Log No.	Total Uranium Conc. (µg/L)	Atom Ratio $^{234}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{236}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{238}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural
Los Alamos Water Supply Wells (Continued):														
Well G-1A	24-May-94	1	UF	11842	0.46	0.0149	1.7%	28.2	7.1E-05	121.3%	0.8	137.38	0.35%	-1.0
Well G-2	24-May-94	1	UF	11841	0.90	0.0119	4.2%	8.5	3.2E-05	552.6%	0.2	135.61	0.47%	-3.5
Well G-2	16-Nov-98	1	UF	16325	0.87	0.0118	2.7%	13.2	2.7E-04	48.1%	2.1	135.98	0.75%	1.9
Well G-4	25-May-94	1	UF	11859	0.92	0.0158	1.8%	28.6	5.7E-05	140.7%	0.7	138.53	0.35%	1.3
San Ildefonso Pueblo Water Supply Wells:														
LA-5	29-Jul-94	1	UF	12407	1.15	0.0136	3.6%	12.4	1.1E-04	60.3%	1.7	138.48	0.35%	1.2
Westside Artesian Well	27-Jul-94	1	UF	12334	22.96	0.0128	2.2%	18.1	6.1E-05	72.1%	1.4	138.80	0.35%	1.9
Eastside Artesian Well	27-Jul-94	1	UF	12395	3.17	0.0159	2.8%	18.8	-6.8E-05	138.3%	-0.7	139.02	0.35%	2.3
Eastside Artesian Well	17-Nov-98	1	UF	15252	0.29	0.0138	2.8%	15.9	7.7E-05	229.5%	0.4	137.62	0.75%	0.3
Halladay House Well	29-Jul-94	1	UF	12409A	1.42	0.0133	1.2%	36.0	5.7E-04	40.4%	2.5	138.58	0.35%	1.4
Halladay House Well	29-Jul-94	LDUP	UF	12409C	1.43	0.0128	2.2%	18.7	-7.9E-05	96.8%	-1.0	138.48	0.35%	1.2
Halladay House Well	29-Jul-94	LTRP	UF	12409B	1.43	0.0126	1.6%	24.6	1.2E-04	49.7%	2.0	138.45	0.35%	1.2
Pajarito Well (Pump 2)	27-Jul-94	1	UF	12336	12.29	0.0110	1.7%	17.8	7.3E-05	93.0%	1.1	138.55	0.45%	1.1
Pajarito Well (Pump 2)	17-Nov-98	1	UF	15239	6.08	0.0166	1.3%	43.0	-9.3E-05	43.0%	-2.3	137.98	0.80%	0.0
Pajarito Well (Pump 2)	17-Nov-98	FDUP	UF	15256	6.17	0.0167	1.9%	28.3	-1.4E-05	-701.6%	-0.1	137.94	0.80%	0.0
Pajarito Well (Pump 2)	17-Nov-98	FTRP	UF	15255	6.06	0.0168	1.4%	37.9	7.9E-05	124.7%	0.8	137.79	0.77%	0.1
Pajarito Well (Pump 2)	17-Nov-98	LDUP	UF	16323	5.94	0.0165	1.1%	47.2	3.4E-04	47.4%	2.1	136.73	0.75%	1.2
Don Juan Playhouse Well	27-Jul-94	1	UF	12394	7.08	0.0140	3.0%	15.0	1.5E-04	73.2%	1.4	138.55	0.35%	1.4
Martinez House Well	27-Jul-94	1	UF	12397	7.81	0.0136	2.2%	20.1	1.1E-05	1184.9%	0.1	138.64	0.35%	1.6
Otowi House Well	29-Jul-94	1	UF	12398	4.27	0.0120	1.7%	20.9	1.8E-04	45.7%	2.2	138.16	0.48%	0.4
New Community Well	17-Nov-98	1	UF	15254	37.19	0.0088	1.7%	7.5	-9.8E-06	443.8%	-0.2	137.93	0.92%	0.0
New Community Well	17-Nov-98	LDUP	UF	16320	36.57	0.0088	1.3%	9.8	1.5E-04	50.9%	2.0	137.21	0.99%	0.5
Old Community Well	27-Jul-94	1	UF	12408A	37.15	0.0090	1.4%	10.8	1.6E-05	278.2%	0.4	139.30	0.35%	2.9
Old Community Well	27-Jul-94	LDUP	UF	12408B	36.85	0.0090	2.0%	7.7	-9.3E-05	70.0%	-1.4	139.19	0.35%	2.7
Old Community Well	17-Nov-98	1	UF	15243	23.65	0.0116	1.5%	21.9	4.1E-05	148.3%	0.7	137.87	0.81%	0.1
Old Community Well	17-Nov-98	LDUP	UF	16321	23.66	0.0114	1.4%	24.3	2.9E-06	2703.0%	0.0	136.40	0.86%	1.3
Sanchez House Well	27-Jul-94	1	UF	12337	6.77	0.0168	1.7%	32.9	-7.0E-05	138.5%	-0.7	138.37	0.39%	0.9

Table A-1 (a). Uranium Isotopic Composition of Groundwaters (TIMS Analyses) (Cont.)

Station Name	Sample Date	Sample Type[a]	Fld. Prep.	Log No.	Total Uranium Conc. (µg/L)	Atom Ratio $^{234}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{236}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{238}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural
Regional Aquifer Springs														
Sacred Spring	28-Jul-94	1	UF	12335	0.91	0.0141	0.5%	91.9	4.5E-05	124.0%	0.8	137.69	0.38%	-0.4
Spring 1	04-Apr-94	1	UF	11789	5.79	0.0144	1.3%	37.2	-6.0E-05	83.2%	-1.2	139.28	0.35%	2.8
Spring 1	27-Sep-94	1	UF	12379	2.29	0.0147	1.4%	33.7	4.8E-05	145.4%	0.7	138.54	0.35%	1.4
Spring 1	28-Sep-98	1	F	15236	1.48	0.0153	1.3%	39.4	5.9E-05	88.8%	1.1	137.80	0.76%	0.1
Spring 2	04-Apr-94	1	UF	11774	3.07	0.0127	1.6%	25.2	-1.7E-05	386.2%	-0.3	139.23	0.35%	2.7
Spring 2	27-Sep-94	1	UF	12380	2.93	0.0122	2.1%	18.0	1.0E-04	39.0%	2.6	138.43	0.35%	1.1
Spring 2	28-Sep-98	1	F	15240	0.81	0.0121	2.1%	17.7	-1.6E-05	533.3%	-0.2	136.14	1.81%	0.7
Sandia Spring	04-Apr-94	1	UF	11779	1.04	0.0127	3.9%	10.3	2.2E-04	29.4%	3.4	139.59	0.35%	3.5
Sandia Spring	27-Sep-94	1	UF	12363	1.01	0.0138	2.2%	20.5	1.4E-04	61.2%	1.6	137.86	0.35%	0.0
Sandia Spring	26-Sep-98	1	F	15237	0.33	0.0130	1.8%	23.2	-7.7E-05	161.4%	-0.6	138.08	0.76%	0.1
Spring 3	04-Apr-94	1	UF	11772	1.49	0.0129	2.2%	18.3	7.4E-05	140.1%	0.7	138.64	0.35%	1.6
Spring 3	27-Sep-94	1	UF	12381	1.30	0.0130	1.4%	29.2	-1.2E-05	440.7%	-0.2	138.35	0.44%	0.8
Spring 3	09-Nov-94	1	UF	12493	2.13	0.0132	1.5%	28.2	1.1E-04	55.2%	1.8	137.68	0.35%	-0.4
Spring 3A	04-Apr-94	1	UF	11777	1.13	0.0129	2.1%	19.9	-5.3E-06	1131.0%	-0.1	138.10	0.35%	0.5
Spring 3A	27-Sep-94	1	UF	12382	1.01	0.0126	1.7%	23.0	-8.0E-05	74.1%	-1.3	138.35	0.44%	0.8
Spring 3AA	27-Sep-94	1	UF	12383	5.84	0.0095	2.8%	7.0	1.5E-05	251.8%	0.4	138.12	0.35%	0.5
Spring 4	27-Sep-94	1	UF	12364	0.88	0.0144	3.3%	14.0	-7.0E-05	261.3%	-0.4	138.56	0.35%	1.4
Spring 4A	05-Apr-94	1	UF	11778	1.01	0.0164	2.1%	26.1	8.3E-07	12055.7%	0.0	139.66	0.35%	3.6
Spring 4A	27-Sep-94	1	UF	12359	0.86	0.0159	2.0%	25.5	-1.1E-05	720.6%	-0.1	138.31	0.41%	0.8
Spring 4A	09-Nov-94	1	UF	12494	1.05	0.0158	1.9%	26.9	1.6E-04	57.4%	1.7	137.38	0.35%	-1.0
Spring 4A	29-Sep-98	1	F	15242	0.46	0.0143	2.2%	21.2	-5.7E-05	116.3%	-0.9	136.65	2.00%	0.5
Spring 5	28-Sep-94	1	UF	12360	0.53	0.0152	2.3%	22.1	6.6E-05	176.0%	0.6	138.40	0.40%	0.9
Ancho Spring	05-Apr-94	1	UF	11775-A	0.65	0.0159	2.0%	26.4	3.4E-04	33.6%	3.0	146.58	0.35%	16.8
Ancho Spring	05-Apr-94	LDUP	UF	11775-B	0.65	0.0151	4.6%	10.8	3.8E-04	61.9%	1.6	147.11	0.38%	16.4
Ancho Spring	01-Jun-94	1	UF	11827	0.67	0.0149	2.4%	20.5	2.7E-04	42.5%	2.4	145.88	0.35%	15.5
Spring 5A	28-Sep-94	1	UF	12374	1.36	0.0124	1.7%	22.9	3.4E-06	2240.4%	0.0	137.40	0.35%	-1.0
Spring 5B	28-Sep-94	1	UF	12376	1.41	0.0134	1.6%	27.7	3.7E-05	174.6%	0.6	138.47	0.35%	1.2
Spring 6	28-Sep-94	1	UF	12373	0.26	0.0137	4.2%	10.6	1.2E-04	200.0%	0.5	137.86	0.36%	0.0

Table A-1 (a). Uranium Isotopic Composition of Groundwaters (TIMS Analyses) (Cont.)

Station Name	Sample Date	Sample Type[a]	Fld. Prep.	Log No.	Total Uranium Conc. (µg/L)	Atom Ratio $^{234}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{236}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{238}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural
Spring 8A	05-Apr-94	1	UF	11773	0.14	0.0131	9.3%	4.4	4.5E-04	98.7%	1.0	138.49	0.45%	1.0
Spring 8A	28-Sep-94	1	UF	12362	0.35	0.0114	6.3%	5.3	1.6E-04	118.2%	0.8	138.43	0.36%	1.1
Spring 8B	28-Sep-94	1	UF	12365	0.14	0.0120	10.3%	3.5	1.2E-04	385.1%	0.3	138.23	0.52%	0.5
Spring 9	30-Sep-94	1	UF	12366	2.78	0.0139	1.1%	40.7	-1.6E-06	3484.3%	0.0	139.46	0.35%	3.2
Spring 9	30-Sep-98	1	F	15238	0.03	0.0149	2.9%	16.7	9.5E-05	360.7%	0.3	137.76	0.74%	0.2
Spring 9A	04-Apr-94	1	UF	11771	0.54	0.0150	2.6%	18.7	4.5E-05	231.0%	0.4	139.00	0.41%	2.0
Spring 9A	30-Sep-94	1	UF	12369	2.94	0.0133	1.6%	27.2	8.6E-05	84.2%	1.2	137.61	0.35%	-0.6
Doe Spring	06-Apr-94	1	UF	11790	0.89	0.0154	2.1%	24.0	1.2E-04	91.3%	1.1	138.48	0.54%	0.8
Doe Spring	30-Sep-94	1	UF	12368	0.22	0.0145	9.8%	4.8	-5.4E-04	62.2%	-1.6	138.23	0.55%	0.5
Spring 10	30-Sep-94	1	UF	12370	2.21	0.0115	1.5%	22.1	8.5E-05	67.6%	1.5	138.01	0.35%	0.3
Canyon Alluvial Groundwater Systems														
Acid/Pueblo Canyons:														
APCO-1	20-Jun-94	1	UF	11913	0.79	0.0098	1.9%	12.1	2.4E-04	42.5%	2.4	125.26	0.35%	-28.5
DP/Los Alamos Canyons:														
LAO-0.7	01-Jan-94	1	UF	11929	7.25	0.0088	1.7%	7.7	0.0001	63.5%	1.6	136.56	0.38%	-2.6
LAOR-1	01-Jan-94	1	UF	11928	6.71	0.0080	1.5%	3.1	0.0001	59.4%	1.7	126.24	0.35%	-26.1
LAO-1	09-Jun-94	1	UF	11891	0.14	0.0084	8.0%	1.2	0.0001	425.3%	0.2	135.68	0.39%	-4.1
LAO-2	09-Jun-94	1	UF	11892	0.09	0.0083	10.1%	0.8	0.0016	21.9%	4.6	76.56	0.36%	-225.5
LAO-3	07-Jun-94	1	UF	11893	0.18	0.0086	10.2%	1.1	0.0003	88.4%	1.1	124.95	0.35%	-29.2
LAO-4	06-Jun-94	1	UF	11894	0.11	0.0088	7.3%	1.8	0.0000	625.3%	-0.2	132.91	0.36%	-10.5
LAO-4.5	06-Jun-94	1	UF	11912	0.16	0.0084	13.2%	0.7	0.0003	76.4%	1.3	131.80	0.37%	-12.5
Mortandad Canyon:														
MCO-4	23-Jun-94	1	UF	11915	1.42	0.0135	1.8%	23.9	1.9E-02	0.9%	107.9	84.18	0.35%	-180.4
MCO-5	23-Jun-94	1	UF	11916	1.86	0.0127	1.5%	26.1	1.5E-02	2.7%	36.5	112.66	0.35%	-63.3
MCO-6	27-Jun-94	1	UF	11917	2.89	0.0130	1.2%	35.4	1.5E-02	1.0%	100.7	117.18	0.35%	-50.0
MCO-7	27-Jun-94	1	UF	11931	4.88	0.0088	2.9%	4.7	1.2E-04	57.5%	1.7	136.78	0.40%	-2.0
MCO-7.5	27-Jun-94	1	UF	11918	0.89	0.0083	2.2%	3.7	-4.6E-05	164.3%	-0.6	138.20	0.35%	0.7

Table A-1 (a). Uranium Isotopic Composition of Groundwaters (TIMS Analyses) (Cont.)

Station Name	Sample Date	Sample Type[a]	Fld. Prep.	Log No.	Total Uranium Conc. (µg/L)	Atom Ratio $^{234}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{236}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{238}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural
Pajarito Canyon:														
PCO-1	22-Jun-94	1	UF	11914	0.04	0.0082	23.2%	0.3	1.6E-04	480.4%	0.2	141.07	0.49%	4.6
PCO-2	22-Jun-94	1	UF	11930	12.66	0.0090	1.4%	10.7	2.3E-04	18.1%	5.5	142.72	0.35%	9.6
Intermediate-Perched Groundwater Systems														
Pueblo/Los Alamos/Sandia Canyon Area Perched System in Conglomerates and Basalt:														
Test Well 1A	31-May-94	UF	1	11861	0.36	0.0108	2.5%	11.7	5.2E-05	182.6%	0.5	137.85	0.35%	-0.1
Test Well 2A	31-May-94	1	UF	11860	0.60	0.0153	1.6%	30.9	2.4E-05	298.6%	0.3	138.65	0.35%	1.6
Basalt Spring	28-Jul-94	1	UF	12410A	0.61	0.0118	1.4%	25.0	9.9E-05	55.3%	1.8	137.38	0.35%	-1.0
East Flank of Jemez Mountains in Bandelier Tuff:														
Water Canyon Gallery	24-May-94	1	UF	11839	0.15	0.0158	3.7%	13.8	-1.0E-04	306.2%	-0.3	135.44	0.48%	-3.7
Water Canyon Gallery	01-Nov-94	1	UF	12332A	0.16	0.0169	3.0%	18.6	7.0E-05	314.1%	0.3	137.99	0.36%	0.2
Water Canyon Gallery	01-Nov-94	LDUP	UF	12332B	0.16	0.0154	4.1%	12.4	2.7E-05	597.3%	0.2	138.00	0.36%	0.3
Water Canyon Gallery	01-Nov-94	LTRP	UF	12332C	0.16	0.0159	3.1%	17.0	2.3E-04	74.1%	1.3	138.03	0.36%	0.3

Table A-1 (b). Uranium Isotopic Composition of Groundwaters

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Atoms ^{234}U/L	Uncert. (1 s)	Atoms ^{235}U/L	Uncert. (1 s)	Atoms ^{236}U/L	Uncert. (1 s)	Atoms ^{238}U/L	Uncert. (1 s)
Regional Aquifer Wells												
Test Wells:												
Test Well 1	31-May-94	1	UF	11862	6.93E+11	1.04%	4.67E+13	0.25%	-2.97E+08	675.7%	6.43E+15	0.25%
Test Well 2	31-May-94	1	UF	11863	2.63E+10	6.72%	1.46E+12	0.49%	8.53E+08	62.4%	1.98E+14	0.25%
Test Well 3	02-Jun-94	1	UF	11895	1.82E+11	1.64%	1.03E+13	0.25%	-7.42E+08	94.9%	1.43E+15	0.25%
Test Well 3	01-Nov-94	1	UF	12330A	1.85E+11	1.19%	1.04E+13	0.25%	-3.23E+08	274.1%	1.44E+15	0.25%
Test Well 3	01-Nov-94	LDUP	UF	12330B	1.89E+11	1.25%	1.04E+13	0.25%	1.24E+09	71.2%	1.44E+15	0.25%
Test Well 4	20-Jun-94	1	UF	11896	1.93E+11	1.76%	9.44E+12	0.25%	1.64E+09	74.6%	1.3E+15	0.25%
Test Well 8	20-Dec-99	1	UF	16356	1.78E+11	1.63%	1.01E+13	0.29%	-8.05E+08	50.3%	1.37E+15	0.68%
Test Well DT-9	27-Sep-94	1	UF	12462	8.58E+10	1.95%	6.07E+12	0.25%	2.10E+08	511.1%	8.4E+14	0.25%
Test Well DT-10	27-Sep-94	1	UF	12463	9.47E+10	2.20%	5.63E+12	0.25%	-3.40E+08	213.4%	7.8E+14	0.25%
Los Alamos Water Supply Wells:												
O-4	24-May-94	1	UF	11843	2.66E+11	3.88%	1.77E+13	1.29%	6.52E+09	74.5%	1.99E+15	0.25%
O-4	01-Nov-94	1	UF	12331-A	2.34E+11	1.14%	1.43E+13	0.25%	1.57E+09	52.3%	1.98E+15	0.25%
O-4	01-Nov-94	LDUP	UF	12331-B	2.38E+11	1.15%	1.43E+13	0.25%	-2.70E+08	273.0%	1.99E+15	0.25%
O-4	16-Nov-98	1	UF	15258	2.29E+11	1.12%	1.22E+13	0.29%	7.73E+08	103.1%	1.67E+15	0.68%
O-4	16-Nov-98	LDUP	UF	16319	2.33E+11	2.32%	1.22E+13	0.39%	2.92E+09	133.4%	1.67E+15	0.69%
O-4	16-Nov-98	FDUP	UF	15246	2.90E+11	2.85%	1.74E+13	0.36%	-3.06E+07	15320.6%	2.37E+15	0.69%
O-4	16-Nov-98	FTRP	UF	15247	2.07E+11	1.19%	9.69E+12	0.30%	8.87E+08	99.1%	1.33E+15	0.68%
PM-2	24-May-94	1	UF	11844	8.00E+10	4.69%	5.56E+12	0.30%	2.11E+08	435.9%	7.72E+14	0.25%
PM-2	17-Nov-98	1	UF	15257	3.69E+09	4.70%	2.62E+11	0.32%	-1.48E+07	899.5%	3.62E+13	0.67%
PM-2	17-Nov-98	LDUP	UF	16324	3.70E+09	12.01%	2.66E+11	0.43%	1.74E+08	224.2%	3.63E+13	0.68%
PM-4	24-May-94	1	UF	11838	1.02E+11	1.78%	6.81E+12	0.25%	3.28E+08	218.0%	9.41E+14	0.25%
PM-5	24-May-94	1	UF	11840	1.33E+11	3.02%	9.73E+12	0.28%	2.72E+09	60.3%	1.34E+15	0.25%
Well G-1A	24-May-94	1	UF	11842	1.25E+11	1.71%	8.41E+12	0.25%	5.96E+08	121.3%	1.16E+15	0.25%
Well G-2	24-May-94	1	UF	11841	1.97E+11	4.16%	1.66E+13	0.40%	5.23E+08	552.6%	2.25E+15	0.25%
Well G-2	16-Nov-98	1	UF	16325	1.91E+11	2.67%	1.61E+13	0.31%	4.42E+09	48.1%	2.19E+15	0.68%
Well G-4	25-May-94	1	UF	11859	2.62E+11	1.79%	1.66E+13	0.25%	9.52E+08	140.7%	2.3E+15	0.25%

Table A-1 (b). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Atoms ^{234}U/L	Uncert. (1 s)	Atoms ^{235}U/L	Uncert. (1 s)	Atoms ^{236}U/L	Uncert. (1 s)	Atoms ^{238}U/L	Uncert. (1 s)
San Ildefonso Pueblo Water Supply Wells:												
LA-5	29-Jul-94	1	UF	12407	2.85E+11	3.54%	2.09E+13	0.25%	2.36E+09	60.3%	2.89E+15	0.25%
Westside Artesian Well	27-Jul-94	1	UF	12334	5.31E+12	2.21%	4.15E+14	0.25%	2.53E+10	72.1%	5.77E+16	0.25%
Eastside Artesian Well	27-Jul-94	1	UF	12395	9.09E+11	2.74%	5.73E+13	0.25%	-3.89E+09	138.3%	7.96E+15	0.25%
Eastside Artesian Well	17-Nov-98	1	UF	15252	7.36E+10	2.80%	5.33E+12	0.31%	4.11E+08	229.5%	7.33E+14	0.68%
Halladay House Well	29-Jul-94	1	UF	12409A	3.42E+11	1.15%	2.58E+13	0.25%	1.46E+10	40.4%	3.57E+15	0.25%
Halladay House Well	29-Jul-94	LDUP	UF	12409C	3.32E+11	2.14%	2.60E+13	0.25%	-2.05E+09	96.8%	3.59E+15	0.25%
Halladay House Well	29-Jul-94	LTRP	UF	12409B	3.27E+11	1.58%	2.60E+13	0.25%	3.13E+09	49.7%	3.6E+15	0.25%
Pajarito Well (Pump 2)	27-Jul-94	1	UF	12336	2.46E+12	1.69%	2.23E+14	0.37%	1.63E+10	93.0%	3.09E+16	0.25%
Pajarito Well (Pump 2)	17-Nov-98	1	UF	15239	1.84E+12	1.20%	1.11E+14	0.37%	-1.03E+10	43.0%	1.53E+16	0.71%
Pajarito Well (Pump 2)	17-Nov-98	FDUP	UF	15256	1.87E+12	1.88%	1.12E+14	0.38%	-1.54E+09	701.6%	1.55E+16	0.70%
Pajarito Well (Pump 2)	17-Nov-98	FTRP	UF	15255	1.86E+12	1.40%	1.11E+14	0.33%	8.76E+09	124.7%	1.52E+16	0.69%
Pajarito Well (Pump 2)	17-Nov-98	LDUP	UF	16323	1.80E+12	1.10%	1.09E+14	0.31%	3.70E+10	47.4%	1.49E+16	0.69%
Don Juan Playhouse Well	27-Jul-94	1	UF	12394	1.79E+12	3.02%	1.28E+14	0.25%	1.87E+10	73.2%	1.78E+16	0.25%
Martinez House Well	27-Jul-94	1	UF	12397	1.92E+12	2.17%	1.42E+14	0.25%	1.50E+09	1184.9%	1.96E+16	0.25%
Otowi House Well	29-Jul-94	1	UF	12398	9.27E+11	1.68%	7.76E+13	0.41%	1.43E+10	45.7%	1.07E+16	0.25%
New Community Well	17-Nov-98	1	UF	15254	5.94E+12	1.65%	6.77E+14	0.48%	-6.61E+09	443.8%	9.34E+16	0.79%
New Community Well	17-Nov-98	LDUP	UF	16320	5.87E+12	1.19%	6.69E+14	0.56%	1.00E+11	50.9%	9.18E+16	0.82%
Old Community Well	27-Jul-94	1	UF	12408A	6.01E+12	1.34%	6.70E+14	0.25%	1.08E+10	278.2%	9.33E+16	0.25%
Old Community Well	27-Jul-94	LDUP	UF	12408B	6.02E+12	2.01%	6.65E+14	0.25%	-6.20E+10	70.0%	9.26E+16	0.25%
Old Community Well	17-Nov-98	1	UF	15243	4.98E+12	1.50%	4.31E+14	0.38%	1.75E+10	148.3%	5.94E+16	0.72%
Old Community Well	17-Nov-98	LDUP	UF	16321	4.96E+12	1.28%	4.36E+14	0.43%	1.26E+09	2703.0%	5.94E+16	0.75%
Sanchez House Well	27-Jul-94	1	UF	12337	2.06E+12	1.63%	1.23E+14	0.30%	-8.58E+09	138.5%	1.7E+16	0.25%
Regional Aquifer Springs												
Sacred Spring	28-Jul-94	1	UF	12335	2.34E+11	0.40%	1.66E+13	0.29%	7.48E+08	124.0%	2.29E+15	0.25%
Spring 1	04-Apr-94	1	UF	11789	1.51E+12	1.24%	1.04E+14	0.25%	-6.27E+09	83.2%	1.45E+16	0.25%
Spring 1	27-Sep-94	1	UF	12379	6.10E+11	1.40%	4.15E+13	0.25%	1.99E+09	145.4%	5.75E+15	0.25%
Spring 1	28-Sep-98	1	F	15236	4.12E+11	1.23%	2.69E+13	0.32%	1.59E+09	88.8%	3.71E+15	0.69%
Spring 2	04-Apr-94	1	UF	11774	7.05E+11	1.57%	5.53E+13	0.25%	-9.61E+08	386.2%	7.7E+15	0.25%

Table A-1 (b). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Atoms ^{234}U/L	Uncert. (1 s)	Atoms ^{235}U/L	Uncert. (1 s)	Atoms ^{236}U/L	Uncert. (1 s)	Atoms ^{238}U/L	Uncert. (1 s)
Regional Aquifer Springs (Continued)												
Spring 2	27-Sep-94	1	UF	12380	6.48E+11	2.06%	5.31E+13	0.25%	5.41E+09	39.0%	7.35E+15	0.25%
Spring 2	28-Sep-98	1	F	15240	1.81E+11	1.25%	1.49E+13	1.68%	-2.37E+08	533.3%	2.03E+15	0.68%
Sandia Spring	04-Apr-94	1	UF	11779	2.38E+11	3.87%	1.87E+13	0.25%	4.10E+09	29.4%	2.61E+15	0.25%
Sandia Spring	27-Sep-94	1	UF	12363	2.55E+11	2.17%	1.84E+13	0.25%	2.58E+09	61.2%	2.54E+15	0.25%
Sandia Spring	26-Sep-98	1	F	15237	7.87E+10	1.75%	6.05E+12	0.34%	-4.68E+08	161.4%	8.35E+14	0.68%
Spring 3	04-Apr-94	1	UF	11772	3.47E+11	2.21%	2.70E+13	0.25%	2.00E+09	140.1%	3.74E+15	0.25%
Spring 3	27-Sep-94	1	UF	12381	3.06E+11	1.38%	2.36E+13	0.27%	-2.94E+08	440.7%	3.26E+15	0.35%
Spring 3	09-Nov-94	1	UF	12493	5.13E+11	1.47%	3.88E+13	0.25%	4.23E+09	55.2%	5.34E+15	0.25%
Spring 3A	04-Apr-94	1	UF	11777	2.66E+11	2.04%	2.06E+13	0.25%	-1.09E+08	1131.0%	2.84E+15	0.25%
Spring 3A	27-Sep-94	1	UF	12382	2.32E+11	1.68%	1.84E+13	0.36%	-1.47E+09	74.1%	2.54E+15	0.25%
Spring 3AA	27-Sep-94	1	UF	12383	1.01E+12	2.81%	1.06E+14	0.25%	1.61E+09	251.8%	1.47E+16	0.25%
Spring 4	27-Sep-94	1	UF	12364	2.29E+11	3.33%	1.59E+13	0.25%	-1.12E+09	261.3%	2.21E+15	0.25%
Spring 4A	05-Apr-94	1	UF	11778	2.97E+11	2.04%	1.81E+13	0.25%	1.50E+07	12055.7%	2.53E+15	0.25%
Spring 4A	27-Sep-94	1	UF	12359	2.49E+11	2.02%	1.57E+13	0.25%	-1.68E+08	720.6%	2.17E+15	0.32%
Spring 4A	09-Nov-94	1	UF	12494	3.03E+11	1.91%	1.92E+13	0.25%	3.02E+09	57.4%	2.63E+15	0.25%
Spring 4A	29-Sep-98	1	F	15242	1.20E+11	1.14%	8.43E+12	1.88%	-4.81E+08	116.3%	1.15E+15	0.68%
Spring 5	28-Sep-94	1	UF	12360	1.47E+11	2.23%	9.68E+12	0.31%	6.42E+08	176.0%	1.34E+15	0.25%
Ancho Spring	05-Apr-94	1	UF	11775-A	1.78E+11	1.95%	1.12E+13	0.25%	3.82E+09	33.6%	1.63E+15	0.25%
Ancho Spring	05-Apr-94	LDUP	UF	11775-B	1.69E+11	4.57%	1.12E+13	0.29%	4.21E+09	61.9%	1.64E+15	0.25%
Ancho Spring	01-Jun-94	1	UF	11827	1.71E+11	2.37%	1.15E+13	0.25%	3.13E+09	42.5%	1.67E+15	0.25%
Spring 5A	28-Sep-94	1	UF	12374	3.09E+11	1.66%	2.49E+13	0.25%	8.45E+07	2240.4%	3.42E+15	0.25%
Spring 5B	28-Sep-94	1	UF	12376	3.43E+11	1.54%	2.55E+13	0.25%	9.46E+08	174.6%	3.54E+15	0.25%
Spring 6	28-Sep-94	1	UF	12373	6.56E+10	4.16%	4.80E+12	0.26%	5.70E+08	200.0%	6.61E+14	0.25%
Spring 8A	05-Apr-94	1	UF	11773	3.36E+10	9.33%	2.58E+12	0.37%	1.16E+09	98.7%	3.57E+14	0.25%
Spring 8A	28-Sep-94	1	UF	12362	7.23E+10	6.29%	6.32E+12	0.25%	1.02E+09	118.2%	8.74E+14	0.25%
Spring 8B	28-Sep-94	1	UF	12365	3.15E+10	10.24%	2.63E+12	0.42%	3.19E+08	385.1%	3.63E+14	0.31%
Spring 9	30-Sep-94	1	UF	12366	6.97E+11	1.08%	5.00E+13	0.25%	-7.76E+07	3484.3%	6.98E+15	0.25%
Spring 9	30-Sep-98	1	F	15238	7.61E+09	2.90%	5.11E+11	0.31%	4.83E+07	360.7%	7.04E+13	0.68%

Table A-1 (b). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Atoms ^{234}U/L	Uncert. (1 s)	Atoms ^{235}U/L	Uncert. (1 s)	Atoms ^{236}U/L	Uncert. (1 s)	Atoms ^{238}U/L	Uncert. (1 s)
Regional Aquifer Springs (Continued)												
Spring 9A	04-Apr-94	1	UF	11771	1.47E+11	2.60%	9.77E+12	0.32%	4.41E+08	231.0%	1.36E+15	0.25%
Spring 9A	30-Sep-94	1	UF	12369	7.13E+11	1.54%	5.36E+13	0.25%	4.61E+09	84.2%	7.38E+15	0.25%
Doe Spring	06-Apr-94	1	UF	11790	2.48E+11	2.07%	1.62E+13	0.28%	1.90E+09	91.3%	2.24E+15	0.46%
Doe Spring	30-Sep-94	1	UF	12368	5.90E+10	9.80%	4.06E+12	0.49%	-2.18E+09	62.2%	5.62E+14	0.25%
Spring 10	30-Sep-94	1	UF	12370	4.62E+11	1.50%	4.02E+13	0.25%	3.43E+09	67.6%	5.54E+15	0.25%
Canyon Alluvial Groundwater Systems												
Acid/Pueblo Canyons:												
APCO-1	20-Jun-94	1	UF	11913	1.55E+11	1.84%	1.58E+13	0.25%	3.77E+09	42.5%	1.97E+15	0.25%
DP/Los Alamos Canyons:												
LAO-0.7	01-Jan-94	1	UF	11929	1.17E+12	1.64%	1.33E+14	0.28%	1.10E+10	63.5%	1.82E+16	0.25%
LAOR-1	01-Jan-94	1	UF	11928	1.07E+12	1.45%	1.34E+14	0.25%	9.64E+09	59.4%	1.69E+16	0.25%
LAO-1	09-Jun-94	1	UF	11891	2.23E+10	8.02%	2.64E+12	0.25%	1.58E+08	425.3%	3.58E+14	0.30%
LAO-2	09-Jun-94	1	UF	11892	2.56E+10	10.05%	3.07E+12	0.25%	4.92E+09	21.9%	2.35E+14	0.25%
LAO-3	07-Jun-94	1	UF	11893	3.12E+10	10.15%	3.63E+12	0.25%	9.76E+08	88.4%	4.54E+14	0.25%
LAO-4	06-Jun-94	1	UF	11894	1.83E+10	7.29%	2.08E+12	0.25%	-9.16E+07	-625.3%	2.77E+14	0.25%
LAO-4.5	06-Jun-94	1	UF	11912	2.63E+10	13.15%	3.13E+12	0.27%	7.94E+08	76.4%	4.13E+14	0.25%
Mortandad Canyon:												
MCO-4	23-Jun-94	1	UF	11915	5.70E+11	1.80%	4.23E+13	0.25%	8.13E+11	0.9%	3.56E+15	0.25%
MCO-5	23-Jun-94	1	UF	11916	5.25E+11	1.50%	4.14E+13	0.25%	6.13E+11	2.7%	4.67E+15	0.25%
MCO-6	27-Jun-94	1	UF	11917	8.05E+11	1.14%	6.19E+13	0.25%	9.23E+11	1.0%	7.26E+15	0.25%
MCO-7	27-Jun-94	1	UF	11931	7.91E+11	2.84%	8.95E+13	0.31%	1.08E+10	57.5%	1.22E+16	0.25%
MCO-7.5	27-Jun-94	1	UF	11918	1.35E+11	2.23%	1.62E+13	0.25%	-7.40E+08	-164.3%	2.24E+15	0.25%
Pajarito Canyon:												
PCO-1	22-Jun-94	1	UF	11914	5.99E+09	23.20%	7.32E+11	0.43%	1.14E+08	480.4%	1.03E+14	0.25%
PCO-2	22-Jun-94	1	UF	11930	2.00E+12	1.38%	2.23E+14	0.25%	5.22E+10	18.1%	3.18E+16	0.25%

Table A-1 (b). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Atoms ^{234}U/L	Uncert. (1 s)	Atoms ^{235}U/L	Uncert. (1 s)	Atoms ^{236}U/L	Uncert. (1 s)	Atoms ^{238}U/L	Uncert. (1 s)
Intermediate Perched Groundwater Systems												
Pueblo/Los Alamos/Sandia Canyon Area Perched System in Conglomerates and Basalt:												
Test Well 1A	31-May-94	1	UF	11861	7.13E+10	2.52%	6.58E+12	0.25%	3.44E+08	182.6%	9.06E+14	0.25%
Test Well 2A	31-May-94	1	UF	11860	1.67E+11	1.60%	1.09E+13	0.25%	2.64E+08	298.6%	1.51E+15	0.25%
Basalt Spring	28-Jul-94	1	UF	12410A	1.33E+11	1.40%	1.12E+13	0.25%	1.11E+09	55.3%	1.54E+15	0.25%
East Flank of Jemez Mountains in Bandelier Tuff:												
Water Canyon Gallery	24-May-94	1	UF	11839	4.54E+10	3.72%	2.86E+12	0.41%	-2.88E+08	-306.2%	3.88E+14	0.25%
Water Canyon Gallery	01-Nov-94	1	UF	12332A	4.88E+10	2.95%	2.88E+12	0.25%	2.02E+08	314.1%	3.98E+14	0.25%
Water Canyon Gallery	01-Nov-94	LDUP	UF	12332B	4.43E+10	4.05%	2.88E+12	0.25%	7.73E+07	597.3%	3.97E+14	0.25%
Water Canyon Gallery	01-Nov-94	LTRP	UF	12332C	4.71E+10	3.05%	2.96E+12	0.25%	6.74E+08	74.1%	4.09E+14	0.25%

Table A-1 (c). Uranium Isotopic Composition of Groundwaters

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Activity ^{234}U (pCi/L)	Uncert. (1 s)	Activity ^{235}U (pCi/L)	Uncert. (1 s)	Activity ^{236}U (pCi/L)	Uncert. (1 s)	Activity ^{238}U (pCi/L)	Uncert. (1 s)	Total Uranium Activity (pCi/L)	Fraction Enriched U	Fraction Depleted U
Regional Aquifer Wells															
Test Wells:															
Test Well 1	31-May-94	1	UF	11862	1.686	1.04%	0.0394	0.25%	-7.53E-06	-675.7%	0.855	0.25%	1.726	0.000946	-0.00036
Test Well 2	31-May-94	1	UF	11863	0.064	6.72%	0.0012	0.49%	2.16E-05	62.4%	0.026	0.25%	0.065	0.015663	-0.00596
Test Well 3	02-Jun-94	1	UF	11895	0.443	1.64%	0.0087	0.25%	-1.88E-05	-94.9%	0.190	0.25%	0.452	-0.00541	0.002058
Test Well 3	01-Nov-94	1	UF	12330A	0.450	1.19%	0.0088	0.25%	-8.18E-06	-274.1%	0.192	0.25%	0.459	-0.00478	0.001818
Test Well 3	01-Nov-94	LDUP	UF	12330B	0.460	1.25%	0.0088	0.25%	3.14E-05	71.2%	0.192	0.25%	0.469	-0.00411	0.001564
Test Well 4	20-Jun-94	1	UF	11896	0.469	1.76%	0.0080	0.25%	4.16E-05	74.6%	0.173	0.25%	0.477	0.000156	-5.9E-05
Test Well 8	20-Dec-99	1	UF	16356	0.433	1.63%	0.0085	0.29%	-2.04E-05	-1.7%	0.182	4.29%	0.441	0.011696	-0.00445
Test Well DT-9	27-Sep-94	1	UF	12462	0.209	1.95%	0.0051	0.25%	5.32E-06	511.1%	0.112	0.25%	0.214	-0.00451	0.001718
Test Well DT-10	27-Sep-94	1	UF	12463	0.230	2.20%	0.0048	0.25%	-8.62E-06	-213.4%	0.104	0.25%	0.235	-0.00362	0.001378
Los Alamos Water Supply Wells:															
O-4	24-May-94	1	UF	11843	0.647	3.88%	0.0149	1.29%	1.65E-04	74.5%	0.265	0.25%	0.663	0.183759	-0.06994
O-4	01-Nov-94	1	UF	12331-A	0.569	1.14%	0.0121	0.25%	3.99E-05	52.3%	0.263	0.25%	0.581	2.42E-05	-9.2E-06
O-4	01-Nov-94	LDUP	UF	12331-B	0.580	1.15%	0.0121	0.25%	-6.86E-06	-273.0%	0.264	0.25%	0.593	-0.00727	0.002766
O-4	16-Nov-98	1	UF	15258	0.558	1.12%	0.0103	0.29%	1.96E-05	3.4%	0.222	4.29%	0.569	0.009698	-0.00369
O-4	16-Nov-98	LDUP	UF	16319	0.566	2.32%	0.0103	0.39%	7.40E-05	4.4%	0.222	4.36%	0.576	0.003558	-0.00135
O-4	16-Nov-98	FDUP	UF	15246	0.705	2.85%	0.0146	0.36%	-7.75E-07	-509.7%	0.315	4.37%	0.720	0.008179	-0.00311
O-4	16-Nov-98	FTRP	UF	15247	0.503	1.19%	0.0082	0.30%	2.25E-05	3.3%	0.177	4.29%	0.511	0.001866	-0.00071
PM-2	24-May-94	1	UF	11844	0.195	4.69%	0.0047	0.30%	5.36E-06	435.9%	0.103	0.25%	0.199	-0.0079	0.003008
PM-2	17-Nov-98	1	UF	15257	0.009	4.70%	0.0002	0.32%	-3.75E-07	-29.9%	0.005	4.28%	0.009	-0.00119	0.000452
PM-2	17-Nov-98	LDUP	UF	16324	0.009	12.01%	0.0002	0.43%	4.41E-06	7.5%	0.005	4.29%	0.009	0.009575	-0.00364
PM-4	24-May-94	1	UF	11838	0.247	1.78%	0.0057	0.25%	8.31E-06	218.0%	0.125	0.25%	0.253	-0.00253	0.000962
PM-5	24-May-94	1	UF	11840	0.324	3.02%	0.0082	0.28%	6.90E-05	60.3%	0.178	0.25%	0.332	0.001636	-0.00062
Well G-1A	24-May-94	1	UF	11842	0.304	1.71%	0.0071	0.25%	1.51E-05	121.3%	0.154	0.25%	0.312	0.003598	-0.00137
Well G-2	24-May-94	1	UF	11841	0.479	4.16%	0.0140	0.40%	1.33E-05	552.6%	0.299	0.25%	0.493	0.016466	-0.00627
Well G-2	16-Nov-98	1	UF	16325	0.464	2.67%	0.0136	0.31%	1.12E-04	1.6%	0.291	4.32%	0.478	0.013775	-0.00524
Well G-4	25-May-94	1	UF	11859	0.637	1.79%	0.0140	0.25%	2.41E-05	140.7%	0.306	0.25%	0.652	-0.00472	0.001796

Table A-1 (c). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Activity ^{234}U (pCi/L)	Uncert. (1 s)	Activity ^{235}U (pCi/L)	Uncert. (1 s)	Activity ^{236}U (pCi/L)	Uncert. (1 s)	Activity ^{238}U (pCi/L)	Uncert. (1 s)	Total Uranium Activity (pCi/L)	Fraction Enriched U	Fraction Depleted U
San Ildefonso Pueblo Water Supply Wells:															
LA-5	29-Jul-94	1	UF	12407	0.694	3.54%	0.0176	0.25%	5.97E-05	60.3%	0.385	0.25%	0.712	-0.00433	0.001649
Westside Artesian Well	27-Jul-94	1	UF	12334	12.919	2.21%	0.3503	0.25%	6.42E-04	72.1%	7.662	0.25%	13.277	-0.0067	0.002549
Eastside Artesian Well	27-Jul-94	1	UF	12395	2.211	2.74%	0.0483	0.25%	-9.85E-05	-138.3%	1.058	0.25%	2.260	-0.00828	0.00315
Eastside Artesian Well	17-Nov-98	1	UF	15252	0.179	2.80%	0.0045	0.31%	1.04E-05	7.6%	0.097	4.30%	0.184	0.001915	-0.00073
Halladay House Well	29-Jul-94	1	UF	12409A	0.832	1.15%	0.0217	0.25%	3.71E-04	40.4%	0.475	0.25%	0.855	-0.00504	0.00192
Halladay House Well	29-Jul-94	LDUP	UF	12409C	0.808	2.14%	0.0219	0.25%	-5.19E-05	-96.8%	0.478	0.25%	0.830	-0.00437	0.001663
Halladay House Well	29-Jul-94	LTRP	UF	12409B	0.795	1.58%	0.0219	0.25%	7.94E-05	49.7%	0.478	0.25%	0.818	-0.00414	0.001574
Pajarito Well (Pump 2)	27-Jul-94	1	UF	12336	5.982	1.69%	0.1878	0.37%	4.12E-04	93.0%	4.101	0.25%	6.174	-0.00489	0.001861
Pajarito Well (Pump 2)	17-Nov-98	1	UF	15239	4.478	1.20%	0.0933	0.37%	-2.61E-04	-1.4%	2.029	4.51%	4.574	-0.00073	0.000276
Pajarito Well (Pump 2)	17-Nov-98	FDUP	UF	15256	4.559	1.88%	0.0947	0.38%	-3.91E-05	-23.3%	2.059	4.46%	4.656	-0.00046	0.000177
Pajarito Well (Pump 2)	17-Nov-98	FTRP	UF	15255	4.513	1.40%	0.0932	0.33%	2.22E-04	4.1%	2.024	4.39%	4.609	0.000623	-0.00024
Pajarito Well (Pump 2)	17-Nov-98	LDUP	UF	16323	4.387	1.10%	0.0920	0.31%	9.37E-04	1.6%	1.983	4.35%	4.481	0.008341	-0.00317
Don Juan Playhouse Well	27-Jul-94	1	UF	12394	4.366	3.02%	0.1082	0.25%	4.74E-04	73.2%	2.363	0.25%	4.476	-0.00485	0.001845
Martinez House Well	27-Jul-94	1	UF	12397	4.683	2.17%	0.1194	0.25%	3.79E-05	1184.9%	2.608	0.25%	4.805	-0.00554	0.002109
Otowi House Well	29-Jul-94	1	UF	12398	2.255	1.68%	0.0654	0.41%	3.62E-04	45.7%	1.424	0.25%	2.322	-0.00205	0.000779
New Community Well	17-Nov-98	1	UF	15254	14.450	1.65%	0.5711	0.48%	-1.68E-04	-14.8%	12.412	4.98%	15.034	-0.00035	0.000135
New Community Well	17-Nov-98	LDUP	UF	16320	14.280	1.19%	0.5644	0.56%	2.53E-03	1.7%	12.202	5.20%	14.856	0.004866	-0.00185
Old Community Well	27-Jul-94	1	UF	12408A	14.621	1.34%	0.5650	0.25%	2.73E-04	278.2%	12.401	0.25%	15.198	-0.01027	0.003908
Old Community Well	27-Jul-94	LDUP	UF	12408B	14.640	2.01%	0.5609	0.25%	-1.57E-03	-70.0%	12.300	0.25%	15.213	-0.00947	0.003606
Old Community Well	17-Nov-98	1	UF	15243	12.128	1.50%	0.3632	0.38%	4.42E-04	4.9%	7.891	4.54%	12.500	5.2E-05	-2E-05
Old Community Well	17-Nov-98	LDUP	UF	16321	12.071	1.28%	0.3673	0.43%	3.20E-05	89.9%	7.895	4.75%	12.446	0.010719	-0.00408
Sanchez House Well	27-Jul-94	1	UF	12337	5.018	1.63%	0.1036	0.30%	-2.17E-04	-138.5%	2.258	0.25%	5.123	-0.00358	0.001363
Regional Aquifer Springs															
Sacred Spring	28-Jul-94	1	UF	12335	0.569	0.40%	0.0140	0.29%	1.89E-05	124.0%	0.304	0.25%	0.583	0.001369	-0.00052
Spring 1	04-Apr-94	1	UF	11789	3.668	1.24%	0.0880	0.25%	-1.59E-04	-83.2%	1.931	0.25%	3.758	-0.01013	0.003857
Spring 1	27-Sep-94	1	UF	12379	1.485	1.40%	0.0350	0.25%	5.05E-05	145.4%	0.764	0.25%	1.521	-0.00482	0.001834
Spring 1	28-Sep-98	1	F	15236	1.003	1.23%	0.0227	0.32%	4.04E-05	3.0%	0.492	4.36%	1.026	0.000609	-0.00023

Table A-1 (c). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Activity ^{234}U (pCi/L)	Uncert. (1 s)	Activity ^{235}U (pCi/L)	Uncert. (1 s)	Activity ^{236}U (pCi/L)	Uncert. (1 s)	Activity ^{238}U (pCi/L)	Uncert. (1 s)	Total Uranium Activity (pCi/L)	Fraction Enriched U	Fraction Depleted U
Regional Aquifer Springs (Continued)															
Spring 2	04-Apr-94	1	UF	11774	1.716	1.57%	0.0467	0.25%	-2.44E-05	-386.2%	1.024	0.25%	1.763	-0.00978	0.003723
Spring 2	27-Sep-94	1	UF	12380	1.576	2.06%	0.0448	0.25%	1.37E-04	39.0%	0.977	0.25%	1.621	-0.00399	0.001517
Spring 2	28-Sep-98	1	F	15240	0.440	1.25%	0.0126	1.68%	-6.02E-06	-17.7%	0.270	4.33%	0.453	0.012612	-0.0048
Sandia Spring	04-Apr-94	1	UF	11779	0.578	3.87%	0.0158	0.25%	1.04E-04	29.4%	0.347	0.25%	0.594	-0.01243	0.004732
Sandia Spring	27-Sep-94	1	UF	12363	0.621	2.17%	0.0156	0.25%	6.55E-05	61.2%	0.338	0.25%	0.637	0.000151	-5.7E-05
Sandia Spring	26-Sep-98	1	F	15237	0.191	1.75%	0.0051	0.34%	-1.19E-05	-5.4%	0.111	4.29%	0.197	-0.00148	0.000564
Spring 3	04-Apr-94	1	UF	11772	0.844	2.21%	0.0227	0.25%	5.07E-05	140.1%	0.497	0.25%	0.867	-0.00552	0.002102
Spring 3	27-Sep-94	1	UF	12381	0.744	1.38%	0.0199	0.27%	-7.45E-06	-440.7%	0.434	0.35%	0.764	-0.00344	0.001309
Spring 3	09-Nov-94	1	UF	12493	1.249	1.47%	0.0327	0.25%	1.07E-04	55.2%	0.710	0.25%	1.282	0.001438	-0.00055
Spring 3A	04-Apr-94	1	UF	11777	0.648	2.04%	0.0174	0.25%	-2.77E-06	-1131.0%	0.378	0.25%	0.665	-0.00161	0.000612
Spring 3A	27-Sep-94	1	UF	12382	0.564	1.68%	0.0155	0.36%	-3.72E-05	-74.1%	0.338	0.25%	0.580	-0.00344	0.001311
Spring 3AA	27-Sep-94	1	UF	12383	2.455	2.81%	0.0895	0.25%	4.08E-05	251.8%	1.948	0.25%	2.546	-0.00174	0.000662
Spring 4	27-Sep-94	1	UF	12364	0.558	3.33%	0.0134	0.25%	-2.84E-05	-261.3%	0.294	0.25%	0.572	-0.00493	0.001877
Spring 4A	05-Apr-94	1	UF	11778	0.723	2.04%	0.0153	0.25%	3.81E-07	12055.7%	0.336	0.25%	0.738	-0.0129	0.004911
Spring 4A	27-Sep-94	1	UF	12359	0.605	2.02%	0.0132	0.25%	-4.25E-06	-720.6%	0.288	0.32%	0.619	-0.00312	0.001188
Spring 4A	09-Nov-94	1	UF	12494	0.737	1.91%	0.0162	0.25%	7.64E-05	57.4%	0.350	0.25%	0.754	0.003653	-0.00139
Spring 4A	29-Sep-98	1	F	15242	0.293	1.14%	0.0071	1.88%	-1.22E-05	-3.9%	0.153	4.30%	0.300	0.008895	-0.00339
Spring 5	28-Sep-94	1	UF	12360	0.358	2.23%	0.0082	0.31%	1.63E-05	176.0%	0.178	0.25%	0.366	-0.00379	0.001444
Ancho Spring	05-Apr-94	1	UF	11775-A	0.432	1.95%	0.0094	0.25%	9.67E-05	33.6%	0.217	0.25%	0.442	-0.06314	0.024032
Ancho Spring	05-Apr-94	LDUP	UF	11775-B	0.412	4.57%	0.0094	0.29%	1.07E-04	61.9%	0.218	0.25%	0.421	-0.06694	0.025478
Ancho Spring	01-Jun-94	1	UF	11827	0.416	2.37%	0.0097	0.25%	7.94E-05	42.5%	0.223	0.25%	0.426	-0.05806	0.022099
Spring 5A	28-Sep-94	1	UF	12374	0.751	1.66%	0.0210	0.25%	2.14E-06	2240.4%	0.454	0.25%	0.773	0.003515	-0.00134
Spring 5B	28-Sep-94	1	UF	12376	0.834	1.54%	0.0215	0.25%	2.40E-05	174.6%	0.470	0.25%	0.856	-0.00429	0.001631
Spring 6	28-Sep-94	1	UF	12373	0.160	4.16%	0.0040	0.26%	1.45E-05	200.0%	0.088	0.25%	0.164	0.000114	-4.3E-05
Spring 8A	05-Apr-94	1	UF	11773	0.082	9.33%	0.0022	0.37%	2.95E-05	98.7%	0.047	0.25%	0.084	-0.00441	0.001679
Spring 8A	28-Sep-94	1	UF	12362	0.176	6.29%	0.0053	0.25%	2.59E-05	118.2%	0.116	0.25%	0.181	-0.00398	0.001515
Spring 8B	28-Sep-94	1	UF	12365	0.077	10.24%	0.0022	0.42%	8.08E-06	385.1%	0.048	0.31%	0.079	-0.00257	0.000979
Spring 9	30-Sep-94	1	UF	12366	1.697	1.08%	0.0422	0.25%	-1.97E-06	-3484.3%	0.927	0.25%	1.740	-0.01148	0.004369
Spring 9	30-Sep-98	1	F	15238	0.019	2.90%	0.0004	0.31%	1.22E-06	12.0%	0.009	4.29%	0.019	0.000857	-0.00033
Spring 9A	04-Apr-94	1	UF	11771	0.357	2.60%	0.0082	0.32%	1.12E-05	231.0%	0.180	0.25%	0.365	-0.00816	0.003106

Table A-1 (c). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Activity ^{234}U (pCi/L)	Uncert. (1 s)	Activity ^{235}U (pCi/L)	Uncert. (1 s)	Activity ^{236}U (pCi/L)	Uncert. (1 s)	Activity ^{238}U (pCi/L)	Uncert. (1 s)	Total Uranium Activity (pCi/L)	Fraction Enriched U	Fraction Depleted U
Regional Aquifer Springs (Continued)															
Spring 9A	30-Sep-94	1	UF	12369	1.734	1.54%	0.0452	0.25%	1.17E-04	84.2%	0.980	0.25%	1.780	0.001955	-0.00074
Doe Spring	06-Apr-94	1	UF	11790	0.603	2.07%	0.0136	0.28%	4.81E-05	91.3%	0.297	0.46%	0.617	-0.00433	0.001649
Doe Spring	30-Sep-94	1	UF	12368	0.144	9.80%	0.0034	0.49%	-5.52E-05	-62.2%	0.075	0.25%	0.147	-0.00252	0.000958
Spring 10	30-Sep-94	1	UF	12370	1.124	1.50%	0.0339	0.25%	8.70E-05	67.6%	0.736	0.25%	1.158	-0.00096	0.000366
Canyon Alluvial Groundwater Systems															
Acid/Pueblo Canyons:															
APCO-1	20-Jun-94	1	UF	11913	0.378	1.84%	0.0133	0.25%	9.56E-05	42.5%	0.262	0.25%	0.391	0.091544	-0.03484
DP/Los Alamos Canyons:															
LAO-0.7	01-Jan-94	1	UF	11929	2.842	1.64%	0.1125	0.28%	2.80E-04	63.5%	2.420	0.25%	2.957	0.009608	-0.00366
LAOR-1	01-Jan-94	1	UF	11928	2.599	1.45%	0.1126	0.25%	2.44E-04	59.4%	2.239	0.25%	2.714	0.084431	-0.03213
LAO-1	09-Jun-94	1	UF	11891	0.054	8.02%	0.0022	0.25%	4.01E-06	425.3%	0.048	0.30%	0.056	0.015967	-0.00608
LAO-2	09-Jun-94	1	UF	11892	0.062	10.05%	0.0026	0.25%	1.25E-04	21.9%	0.031	0.25%	0.065	0.444886	-0.16932
LAO-3	07-Jun-94	1	UF	11893	0.076	10.15%	0.0031	0.25%	2.47E-05	88.4%	0.060	0.25%	0.079	0.093849	-0.03572
LAO-4	06-Jun-94	1	UF	11894	0.044	7.29%	0.0018	0.25%	-2.32E-06	-625.3%	0.037	0.25%	0.046	0.036033	-0.01371
LAO-4.5	06-Jun-94	1	UF	11912	0.064	13.15%	0.0026	0.27%	2.01E-05	76.4%	0.055	0.25%	0.067	0.044126	-0.01679
Mortandad Canyon:															
MCO-4	23-Jun-94	1	UF	11915	1.387	1.80%	0.0356	0.25%	2.06E-02	0.9%	0.473	0.25%	1.423	0.389624	-0.14829
MCO-5	23-Jun-94	1	UF	11916	1.277	1.50%	0.0349	0.25%	1.55E-02	2.7%	0.620	0.25%	1.312	0.183025	-0.06966
MCO-6	27-Jun-94	1	UF	11917	1.958	1.14%	0.0522	0.25%	2.34E-02	1.0%	0.964	0.25%	2.011	0.150206	-0.05717
MCO-7	27-Jun-94	1	UF	11931	1.924	2.84%	0.0755	0.31%	2.75E-04	57.5%	1.627	0.25%	2.001	0.007948	-0.00303
MCO-7.5	27-Jun-94	1	UF	11918	0.328	2.23%	0.0137	0.25%	-1.88E-05	-164.3%	0.297	0.25%	0.342	-0.00234	0.000891
Pajarito Canyon:															
PCO-1	22-Jun-94	1	UF	11914	0.015	23.20%	0.0006	0.43%	2.88E-06	480.4%	0.014	0.25%	0.015	-0.02316	0.008816
PCO-2	22-Jun-94	1	UF	11930	4.877	1.38%	0.1880	0.25%	1.32E-03	18.1%	4.227	0.25%	5.069	-0.03513	0.013369
Intermediate Perched Groundwater Systems															
Pueblo/Los Alamos/Sandia Canyon Area Perched System in Conglomerates and Basalt:															
Test Well 1A	31-May-94	1	UF	11861	0.173	2.52%	0.0055	0.25%	8.71E-06	182.6%	0.120	0.25%	0.179	0.00025	-9.5E-05
Test Well 2A	31-May-94	1	UF	11860	0.406	1.60%	0.0092	0.25%	6.68E-06	298.6%	0.201	0.25%	0.415	-0.00561	0.002136
Basalt Spring	28-Jul-94	1	UF	12410A	0.324	1.40%	0.0095	0.25%	2.81E-05	55.3%	0.205	0.25%	0.333	0.003592	-0.00137

Table A-1 (c). Uranium Isotopic Composition of Groundwaters (Cont.)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Activity ^{234}U (pCi/L)	Uncert. (1 s)	Activity ^{235}U (pCi/L)	Uncert. (1 s)	Activity ^{236}U (pCi/L)	Uncert. (1 s)	Activity ^{238}U (pCi/L)	Uncert. (1 s)	Total Uranium Activity (pCi/L)	Fraction Enriched U	Fraction Depleted U
East Flank of Jemez Mountains in Bandelier Tuff:															
Water Canyon Gallery	24-May-94	1	UF	11839	0.110	3.72%	0.0024	0.41%	-7.31E-06	-306.2%	0.052	0.25%	0.113	0.017738	-0.00675
Water Canyon Gallery	01-Nov-94	1	UF	12332A	0.119	2.95%	0.0024	0.25%	5.13E-06	314.1%	0.053	0.25%	0.121	-0.00083	0.000316
Water Canyon Gallery	01-Nov-94	LDUP	UF	12332B	0.108	4.05%	0.0024	0.25%	1.96E-06	597.3%	0.053	0.25%	0.110	-0.00091	0.000345
Water Canyon Gallery	01-Nov-94	LTRP	UF	12332C	0.115	3.05%	0.0025	0.25%	1.71E-05	74.1%	0.054	0.25%	0.117	-0.0011	0.000419

Notes: [a]Sample Type: 1 = primary sample; LDUP = Laboratory duplicate sample; LTRP = Laboratory triplicate sample; FDUP = Field duplicate sample; FTRP = Field triplicate sample.

[b]Fld Prep: UF = Non-filtered sample; F = filtered (0.45 µm pore size filter) sample.

[C]Uncert: Total propagated uncertainty 1s (1 sigma or 1 standard deviation).

Table A-2 (a). Uranium Isotopic Composition of Surface Waters (TIMS Analyses)

Station Name	Sample Date	Sample Type	Fld. Prep.	Log No.	Total Uranium Conc. (µg/L)	Atom Ratio $^{234}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{236}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Atom Ratio $^{238}U/^{235}U$	Uncert. (1 s)	No. Sigma From Natural	Fraction Enriched U	Fraction Depleted U
Chaquehui at Rio Grande	09-29-94	1	UF	12367	0.596	0.0146	2.9%	16.4	7.17E-05	143.2%	0.7	138.08	0.35%	0.4	-0.0015	0.0006
Cochiti Middle	06-Apr-94	1	UF	11787	0.085	0.0115	9.4%	3.6	2.92E-04	135.6%	0.7	141.34	0.72%	3.4	-0.0251	0.0096
Frijoles at Monument HQ	28-Jun-94	1	UF	11857	0.411	0.0152	2.4%	20.9	-4.47E-05	309.1%	-0.3	138.22	0.36%	0.7	-0.0025	0.0009
Frijoles at Rio Grande	30-Sep-94	1	UF	12371	0.087	0.0054	33.3%	-1.2	6.00E-04	113.7%	0.9	138.82	0.42%	1.6	-0.0068	0.0026
Frijoles at Rio Grande	06-Apr-94	1	UF	11780	0.084	0.0092	12.0%	1.4	7.32E-04	60.0%	1.7	141.06	0.42%	5.4	-0.0230	0.0088
Los Alamos Canyon Reservoir	14-Jul-94	1	UF	11932	0.102	0.0109	8.3%	3.6	-5.70E-04	59.8%	-1.7	138.58	0.76%	0.7	-0.0051	0.0019
Mortandad at GS-1	23-Jun-94	1	UF	11897	0.384	0.0107	2.9%	9.9	1.08E-02	1.9%	52.2	126.29	0.35%	-25.9	0.0841	-0.0320
Pajarito Canyon	20-May-94	1	UF	12378	0.889	0.0150	14.6%	3.4	1.17E-04	69.3%	1.4	138.33	0.38%	0.9	-0.0033	0.0013
Rio Grande at Frijoles (bank)	29-Sep-94	1	UF	12372	0.736	0.0114	2.6%	12.9	3.69E-05	243.0%	0.4	136.92	0.35%	-2.0	0.0070	-0.0027
Rio Grande below LA Canyon	04-Apr-94	1	UF	11788	1.941	0.0122	2.9%	13.0	-2.78E-04	51.1%	-2.0	138.86	0.35%	2.0	-0.0071	0.0027

Table A-2 (b). Uranium Isotopic Composition of Surface Waters

Station Name	Sample Date	Log No.	Atoms ^{234}U/L	Uncert. (1 s)	Atoms ^{235}U/L	Uncert. (1 s)	Atoms ^{236}U/L	Uncert. (1 s)	Atoms ^{238}U/L	Uncert. (1 s)
Chaquehui at Rio Grande	09-29-94	12367	1.58E+11	2.9%	1.08E+13	0.25%	7.77E+08	143.25%	1.5E+15	0.25%
Cochiti Middle	06-Apr-94	11787	1.74E+10	9.3%	1.51E+12	0.67%	4.42E+08	135.62%	2.14E+14	0.25%
Frijoles at Monument HQ	28-Jun-94	11857	1.14E+11	2.4%	7.47E+12	0.26%	-3.34E+08	309.08%	1.03E+15	0.25%
Frijoles at Rio Grande	30-Sep-94	12371	8.59E+09	33.2%	1.58E+12	0.33%	9.47E+08	113.74%	2.19E+14	0.25%
Frijoles at Rio Grande	06-Apr-94	11780	1.37E+10	12.0%	1.5E+12	0.34%	1.10E+09	60.04%	2.11E+14	0.25%
Los Alamos Canyon Reservoir	14-Jul-94	11932	2.00E+10	8.3%	1.84E+12	0.72%	-1.05E+09	59.84%	2.55E+14	0.25%
Mortandad at GS-1	23-Jun-94	11897	8.15E+10	2.9%	7.62E+12	0.25%	8.26E+10	1.90%	9.63E+14	0.25%
Pajarito Canyon	20-May-94	12378	2.42E+11	14.6%	1.61E+13	0.25%	1.89E+09	69.27%	2.23E+15	0.28%
Rio Grande at Frijoles (bank)	29-Sep-94	12372	1.54E+11	2.5%	1.35E+13	0.25%	4.99E+08	243.02%	1.85E+15	0.25%
Rio Grande below LA Canyon	04-Apr-94	11788	4.30E+11	2.9%	3.51E+13	0.25%	-9.75E+09	51.14%	4.88E+15	0.25%

Table A-2 (c). Uranium Isotopic Composition of Surface Waters

Station Name	Log No.	Activity ^{234}U (pCi/L)	Uncert. (1 s)	Activity ^{235}U (pCi/L)	Uncert. (1 s)	Activity ^{236}U (pCi/L)	Uncert. (1 s)	Activity ^{238}U (pCi/L)	Uncert. (1 s)	Total Uranium Activity (pCi/L)
Chaquehui at Rio Grande	12367	0.3856	2.90%	0.0009	0.25%	1.97E-05	143.25%	0.1988	0.25%	0.585
Cochiti Middle	11787	0.0424	9.35%	0.0001	0.67%	1.12E-05	135.62%	0.0284	0.25%	0.071
Frijoles at Monument HQ	11857	0.2769	2.37%	0.0006	0.26%	-8.47E-06	309.08%	0.1372	0.25%	0.415
Frijoles at Rio Grande	12371	0.0209	33.25%	0.0001	0.33%	2.40E-05	113.74%	0.0291	0.25%	0.050
Frijoles at Rio Grande	11780	0.0334	12.01%	0.0001	0.34%	2.78E-05	60.04%	0.0281	0.25%	0.062
Los Alamos Canyon Reservoir	11932	0.0487	8.27%	0.0002	0.72%	-2.66E-05	59.84%	0.0339	0.25%	0.083
Mortandad at GS-1	11897	0.1982	2.87%	0.0007	0.25%	2.09E-03	1.90%	0.1279	0.25%	0.329
Pajarito Canyon	12378	0.5895	14.64%	0.0014	0.25%	4.78E-05	69.27%	0.2968	0.28%	0.888
Rio Grande at Frijoles (bank)	12372	0.3750	2.54%	0.0012	0.25%	1.26E-05	243.02%	0.2457	0.25%	0.622
Rio Grande below LA Canyon	11788	1.0458	2.88%	0.0030	0.25%	-2.47E-04	51.14%	0.6478	0.25%	1.696

Notes: [a]Sample Type: 1 = primary sample; LDUP = Laboratory duplicate sample; LTRP = Laboratory triplicate sample; FDUP = Field duplicate sample; FTRP = Field triplicate sample.

[b]Fld Prep: UF = Non-filtered sample; F = filtered (0.45 µm pore size filter) sample.

[C]Uncert: Total propagated uncertainty 1s (1 sigma or 1 standard deviation).

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